U.S. Fish & Wildlife Service

Handbook for Mosquito Management on National Wildlife Refuges

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"The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans."

National Wildlife Refuge System Improvement Act of 1997

Photo credit: Don Brubaker, USFWS, 2011

Joy Albertson, Supervisory Wildlife Biologist, San Francisco Bay NWRC, and Jason Sequeira, Field Supervisor, Marin/ Sonoma Mosquito Control, and Vector District, CA dipping for mosquito larvae at San Pablo Bay National Wildlife Refuge.

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Introduction

The U.S. Fish and Wildlife Service (Service) considers native mosquitoes a part of the natural ecosystem in the National Wildlife Refuge System (Refuge System) habitats in which they occur. The Service allows mosquitoes on refuges to exist unimpeded unless they pose a specific human or wildlife health risk. Sometimes Refuge Managers are called upon to manage mosquitoes on-refuge in coordination with local public health or mosquito control organizations. This handbook applies to mosquito management activities related to reducing risks to public health from mosquito-borne disease.

A Refuge Manager may authorize others to conduct mosquito management activities on a refuge to protect public health when local, current mosquito monitoring data provided by the public health agency or an authorized designated representative indicate that mosquitoes on the refuge are causing, or are expected to cause, a public health threat. Mosquito management includes the following activities: planning, identification and inventory of mosquito species, surveillance and monitoring, establishing action thresholds, prevention, control (to suppress and/or reduce mosquitoes), restoration, research, and outreach and education activities used to minimize risks to public health. All Refuge System mosquito management activities, including Service planning documents, must be consistent with all applicable Federal laws, regulations and policies.

Unless mosquitoes interfere with refuge-specific management goals and objectives, or cause a public or wildlife health risk, they are allowed to exist unimpeded on a refuge. Mosquito-vectored pathogens that cause disease are the primary public health concern associated with mosquitoes on a refuge. When faced with mosquito management decisions affecting Refuge System lands and waters, the Service's position is to work with public health agencies and/or mosquito control organizations using the most effective method or combination of methods that pose the lowest risk to fish, wildlife, and their habitats. Often, the Service's preferred mosquito management option is to use non-pesticide based tools.

Under Service policy, integrated pest management (IPM) is a sustainable approach to managing pests by combining physical, biological, cultural, and chemical tools in a way that minimizes health, environmental and economic risk. Effective mosquito management on refuges requires planning that follows the IPM principles. This handbook for mosquito management is a stepdown handbook for the Service IPM policy (569 FW 1).

Purpose and Scope of this Handbook

This handbook establishes the Service's interpretation of existing laws, regulations, and policies that allow us to authorize mosquito management activities on Refuge System lands and waters. The handbook provides consistency in the decision-making process regarding mosquito management on national wildlife refuges for protection of public health. In general, the Service does not treat for mosquito-vectored wildlife disease. The handbook guides development of Mosquito Management Plans (MMP) in compliance with the National Environmental Policy Act and provides information to make informed management decisions and minimize the impacts to natural resources from mosquito management activities on Refuge System lands and waters. Mosquito control activities may include prevention practices, habitat management actions, biological controls, chemical treatments, and, potentially, modified mosquitoes. Mosquito management planning is most effective when conducted in partnership with public health authorities or their authorized representatives. Such representatives are often mosquito control or mosquito abatement districts (referred to throughout the handbook as "mosquito control organizations").

Mosquito management planning includes identifying acceptable control strategies. An MMP serves as an important tool to communicate with the community and provides common understanding of acceptable and permitted mosquito management strategies among the health authority, mosquito control organization, and the refuge staff.

Planning is necessary to ensure that mosquito management activities on a refuge are compatible with the establishing purposes of the refuge. Mosquitoes are a part of the ecosystem; they serve as a food resource for other organisms. Nevertheless, they are also pathogen vectors. Generally, the Service receives no appropriated funds to conduct mosquito management activities and implementation of monitoring and treatment on-refuge is conducted by public health or the mosquito management organizations. Mosquito management activities on refuges are considered a use of a refuge and require a Special Use Permit (SUP).

The Service relies on public health authorities and mosquito control organizations to determine the risks and threats to public health related to mosquito-borne pathogens and to advise us on management actions to minimize these risks. Public health authorities may work with refuge staff to implement integrated pest management principles that include the following:

(1) Identifying mosquito species in the area and understanding their life history and conditions that support their production;

(2) Monitoring mosquitoes and mosquito-borne pathogen surveillance (as needed) to provide relevant information to refuge staff;

(3) Establishing action thresholds that help the Refuge Managers make informed decisions about actions such as pesticide treatments, when needed;

(4) Recording decisions and effectiveness of actions implemented; and

(5) Monitoring for efficacy, compliance, and non-target impacts.

Mosquito management planning for a national wildlife refuge must consider public health while protecting natural resources. Pesticides used to manage mosquitoes have the potential to adversely impact non-target species either directly or indirectly. Some mosquito control pesticides impact the immune, reproductive, or nervous system of insects. Some larvicides kill susceptible chironomid (midge) larvae, with research suggesting that population-level impacts may affect the food web at the community-level. Mosquito adulticide products are broad-spectrum insecticides that may impact a wide variety of invertebrates and vertebrates.

The degree to which mosquito control pesticides may impact non-target organisms or non-target insect communities is often difficult to predict because of differences in sensitivity among species, differences in toxicity of various formulated products, and basic knowledge gaps in species-specific toxicity. There are few studies that examine the non-target impacts of mosquito control pesticides at diverse spatial and temporal scales. The use of mosquito larvicides is considered preferable to mosquito adulticides for several reasons:

(1) Larvicides prevent the emergence of adults;

(2) Larvicides can provide up to a month (or longer) of control, rather than the few hours provided by adulticides;

(3) Most larvicides are far less toxic than adulticides; and

(4) Larvicides are generally applied to smaller spatial areas, thus impacting fewer non-target resources.

For these reasons and in view of the mission of the Refuge System, when mosquito management actions include pesticide use, they should target the mosquito larval stage. Mosquito larvicides / pupacides pose less risk than adulticide products to non-target species and the environment.

This handbook guides Service review, planning, and authorization processes for use of lawfully registered pesticides for mosquito control on-refuge. The U.S. Environmental Protection Agency (USEPA) assesses human health and non-target resource risks of pesticides during the pesticide registration process. There is increasing attention to mosquito species evolving resistance to mosquito pesticide products currently in use. Uncertainty about human health risks of pesticides, non-target resources impacts, and resistance is ever changing; that is why, in part, that the USEPA conducts pesticide re-registration reviews. These concerns support an integrated approach to mosquito management.

This handbook is applicable to all units of the Refuge System where the Service has jurisdiction over mosquito management activities, regardless of whether the Service or a Service-authorized entity conducts the mosquito management actions.

Principles of Integrated Pest Management (IPM)

Integrated Pest Management is a sustainable approach to managing pests by combining physical, biological, cultural, and chemical tools in a way that minimizes economic, health, and environmental risk. These IPM principles are the foundation for mosquito management planning and implementation.

The Principles of Integrated Pest Management

- **Understand the refuge management objectives and establish short- and long-term priorities.** Refuge objectives would be found in the Comprehensive Conservation Plan (CCP) or in the Habitat Management Plan, or both. Decide on your refuge objectives for mosquito management; use specific, measurable, achievable, realistic, and time-based objectives when choosing tools. *Example: Due to past history of mosquito-vectored disease in the area, a Refuge Manager may allow a public health district or a mosquito control organization to treat some mosquito breeding habitat on the refuge for larval mosquitoes if the public health district requests it.*

- **Prevent mosquitoes from becoming a pest at your site.** This is the first line of defense against any pest species. See the Best Management Practices (BMPs) section of the handbook.

- **Identify and monitor the pest species (mosquito), and know the life history, and the conditions that support the pest(s)**. Similarly, know the diseases that are vectored by the mosquitoes that occur in your area. *The Centers for Disease Control and Prevention (CDC), public health agencies, and mosquito control organizations have relevant information. Access information on the CDC website located at https://www.cdc.gov/niosh/topics/outdoor/mosquito-borne/*

- **Understand the physical (air, water, food, shelter, temperature, and light) and biological factors that affect the number and distribution of mosquitoes and any natural enemies.** Conserve natural enemies when implementing any strategy. Integrated marsh management, for example, can restore high marsh pools to serve as native fish reservoirs in areas that had been previously drained.

- **Build partnerships and consensus with stakeholders, such as communities and decision-makers.** Example: Public health agency staff and technical experts such as mosquito control organization staff. Partnership building is an on-going effort throughout the process.

- **Review available tools and BMPs for mosquito management.** Tools and strategies can include: 1) no action, 2) physical (manual and mechanical), 3) cultural, 4) biological, and 5) chemicals.

- **Establish the "action threshold" at which a management action will be implemented to control the pest population.** (Action thresholds are a key Mosquito Management Plan (MMP) element and are discussed in detail later in the handbook.)

- **Obtain approval, define responsibilities, and implement preventive and best management practices (BMPs) and control treatments, in accordance with applicable laws, regulations, policies and the refuge MMP.**

- **Practice adaptive management.** Evaluate results of implemented management strategies through authorized monitoring; determine if objectives have been achieved, and modify strategies, if necessary.

- **Maintain written records.** Document decisions and report treatments implemented and monitoring results.

- **Outreach and education.** Inform refuge staff of the mosquito management issues in and around the refuge, and prepare informative materials for outreach to visitors.

Mosquito Management Plan

If mosquito management activities occur on or impact a refuge, then refuge staff should prepare an MMP. An MMP is a step-down management plan with specific objectives and strategies that support the objectives identified in a CCP. An MMP is also identified as an integrated pest management plan. Mosquito management planning provides the Service with the opportunity to assess the impacts of mosquito management activities and helps to ensure the protection of natural resources. Mosquito management planning facilitates the development of the working relationships with the local public health authorities and mosquito control organizations. Regardless of refuge-specific circumstances, collaborating with experts who work for local public health authorities or mosquito control organizations will help refuge staff plan for mosquito management. Planning also provides transparency of operations and public inclusion in decision-making. The MMP may include the following sections where appropriate, recognizing the need for refuge-specific flexibility in planning.

National Wildlife Refuge Mosquito Management Plan

Statement of Purpose and Need
Refuge Natural Resources (including maps)
Mosquito Ecology, Life History, and Pathogen Transmission
Climate Change Influences
Health Considerations - Human and Animal
Mosquito-vectored Pathogen Surveillance and Mosquito Monitoring
Mosquito Management Options
- **Best Management Practices**
  - **Managing Habitats for Mosquito Source Reduction**
  - **Mosquito Control Products**
    - **Larvicides, Pupacides, Adulticides**
    - **Modified Mosquitoes**

Thresholds for Action - Risk Management
Pesticide Treatment Decisions
Human Health Emergencies
Natural Resource and Compliance Monitoring and Reporting
Natural Resources Monitoring
Mosquito Management Implementation Compliance Monitoring
Reporting
Adaptive Management
Education and Outreach
- **Local Mosquito Situation and Communication**
- **Prevention**
- **Natural Mosquito Predators**

I. Statement of Purpose and Need

> ∑ State the purpose of the refuge MMP and clearly articulate the public health need for mosquito management on the refuge.

Relate the need for mosquito management planning to refuge goals and objectives, as appropriate. For example, if the refuge provides habitat for a federally listed butterfly, then mosquito management planning might be crucial to minimize impacts to the species and its habitat while conducting mosquito management control activities.

II. Refuge Natural Resources

> ∑ Summarize the natural resources and potential impacts from mosquito management.

A thorough review of the natural resources and the impacts of the mosquito management actions, such as habitat manipulation or effects of pesticides on the natural resources, is necessary. Natural resource descriptions are often presented in an Environmental Assessment as part of National Environmental Policy Act (NEPA) compliance; however, if natural resources have been addressed within another NEPA-compliant planning process, such as in a CCP, then you can incorporate that review by reference.

As a publicly vetted document, appropriate CCP chapter(s) on natural resources can be copied or cited into the Natural Resources section of the MMP. Potential content may include, but is not limited to:

- Distribution and abundance of fish, wildlife, and plant populations, including any threatened or endangered species and related habitats;
- Wildlife habitat and species' relationships that may be impacted by mosquito management;
- Ability of the refuge to meet the habitat needs of fish, wildlife, and plants;
- Context of the refuge in relation to the surrounding ecosystem;
- Structures, components, and functions of the ecosystem(s) of which the refuge is a part;
- Rare or declining fish, wildlife, and plants and their habitats and communities; and
- Special management areas (e.g., wild, scenic, and recreational river areas; wilderness areas).

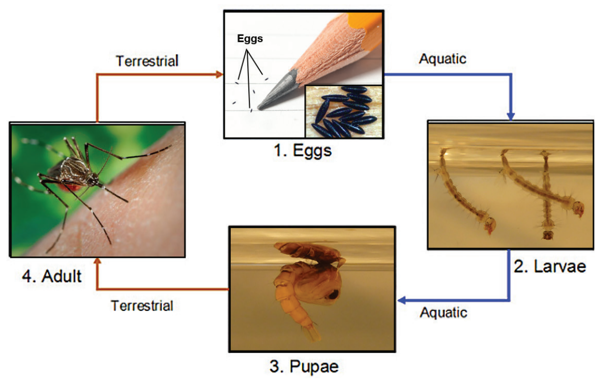
III. Mosquito Ecology, Life History, and Pathogen Transmission

> ∑ Summarize the inventory of mosquito species on refuge and their potential as pathogen vectors.

This handbook focuses on mosquito management planning and decision-making as required for the purposes of protecting public health from diseases caused by mosquito-vectored pathogens regardless of whether vectored by a native or non-native mosquito species. Over 80 million years and the evolution of 3,500 mosquito species, there are now over 175 species of native and non-native mosquitoes in the contiguous United States. Not all mosquito species are vectors of disease. Mosquitoes vary in pathogen transmission efficiency, habitat and host requirements, and, therefore, they may require different control strategies. Many native mosquito species are prey for other aquatic and terrestrial fauna and because of their role in ecosystems, thorough planning is necessary to minimize impacts when mosquito management actions are implemented on refuge to protect public health.

Inventory and identification of the mosquito species that reproduce on the refuge is fundamental information in mosquito management planning. In the MMP, include an inventory of the mosquito species known or suspected to occur on and near the refuge and brief life histories. Species that may vector disease pathogens are particularly important to include. This handbook does not provide life histories because they are readily available online. Sources for determining species of mosquitoes currently occurring on or near a refuge are usually available on websites of the local mosquito control organizations, and from the State and local public health authorities. If there is no current inventory of the mosquitoes species that occur on or near the refuge, contact the local mosquito control organization or public health agency to conduct an inventory. This is not a refuge function. A current mosquito inventory is necessary because the species occurrence may change with climate change or other introductions, such as global transport.

In the aquatic environment, mosquitoes are most effectively managed in the larval and pupal life-cycle stages (Figure 1) https://www.cdc.gov/Dengue/entomologyEcology/m_lifecycle.html.



It takes a mosquito between 4 to 30 days to develop from an egg to an adult, depending on species and water temperature. Mosquito larvae develop through four instars. Skilled observers can determine the instar of larvae and infer hatching or adult emergence time. Instar information is critical for proper timing of larvicide or pupacide applications for maximum effectiveness to help avert the need to use mosquito adulticides. Mosquito control organization staff are usually skilled in mosquito life stage identification; we do not expect the refuge staff to conduct this identification.

IV. Climate Change Influences

∑ Provide a summary of how climate change could influence mosquito production and habitats on your refuge.

Changing environments, whether naturally or through actions taken to restore habitats, may result in increased or decreased mosquito production. Climate change effects may include increased rainfall that creates ponded water, or decreased precipitation and drought conditions that reduce mosquito habitats (IPCC 2013). Sea level rise may alter a landscape so that areas where mosquitoes have never been an issue eventually become a concern. For example, salt marsh mosquitoes may come to inhabit areas further inland than they did historically. Over the past few decades, the effects of climate change have become more measurable in coastal wetlands. Signs of climate change include increased sea levels, marsh edge erosion from intense storms, and conversion of vegetated salt marshes to open water. Wherever there is increased standing water, mosquitoes are more likely to occur. Managers must continue to adapt strategies to the changing landscape and consider mosquito production in management and also periodically update the mosquito inventory on the refuge.

Some scientists have reported that higher global temperatures will enhance transmission rates of mosquito-borne diseases (Shope 1991). Others suggest that the geographic range of diseases will change (Hales et al. 2002). Gubler et al. (2001) reviewed the response of vector-borne pathogens to climate changes and suggested that climate changes will likely affect transmission patterns - some may increase and some may decrease - and that we need to understand more about how pathogens persist and what conditions trigger amplification before the role of the weather and long-term climate trends can be determined. Reiter (2001) argued that the histories of malaria, yellow fever, and dengue suggest that human activities and their impact on local ecology have generally been more significant determinants of disease prevalence than climate. Since climate change scenarios differ across the country and depend highly on local conditions, refuge staff should consult local models as they develop their mosquito management strategies.

V. Health Considerations

∑ Briefly identify and describe the health considerations that drive the MMP on the refuge.

Mosquito-vectored pathogens that cause disease are the primary public health concern associated with mosquitoes. Health considerations related to mosquitoes vary depending on the species present, abundance, geographic area, and time of year. For most refuges and the surrounding communities, public health authorities and their authorized, designated representatives, such as a mosquito control organization, are responsible for surveillance of mosquito-vectored disease, and control treatments, where needed.

Examples of Mosquito-Borne Diseases in the United States

- West Nile Virus
- Dengue Fever
- Chikungunya
- La Crosse Encephalitis
- Eastern Equine Encephalitis
- St. Louis Encephalitis
- Western Equine Encephalitis
- Zika Virus

Mosquito-Borne Disease

An MMP must identify which mosquito-borne diseases may be vectored by mosquitoes that breed on the refuge, either historically or currently. This information is helpful to identify source-area control. Brief summaries of diseases and mosquito-related health conditions that are potentially of concern to refuges are provided in Appendix B. Consult the Centers for Disease Control and Prevention or your State and local mosquito control organization and public health authorities for current local information. The Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases website provides links to useful mosquito-vectored pathogen and related diseases information, https://www.cdc.gov/ncezid/. The U.S. Geological Survey also provides current maps of mosquito-borne disease in the U.S. at: https://diseasemaps.usgs.gov/mapviewer/ . If there are no current or historical occurrences of mosquito-borne diseases in the refuge area, document that fact and the source of the information in the MMP.

Other Mosquito-Related Human Health Considerations

There are other human health considerations associated with mosquitoes. Most of the human population at any given time will have some reactivity to mosquito bites. Outdoor workers, young children, immuno-deficient people, and visitors to an area with indigenous mosquitoes to which they have not been previously exposed are at increased risk for severe reactions to mosquito bites. Though allergic reactions to mosquito bites are common, the clinical diagnosis of "mosquito allergy" is reserved for those with atypical or systemic reactions that may occur in otherwise healthy individuals within hours of a mosquito bite and can last for 3 to 10 days. With any break in the skin, there is the potential for secondary (indirect) bacterial infection resulting from mosquito bites. Anaphylactic reactions (life-threatening, whole-body allergic reaction) to mosquito bites are extremely rare. Appendix B provides a non-exhaustive reference list and more information on mosquito-associated health considerations.

Animal Health Considerations

Animal health can be affected by mosquito-borne diseases. This handbook guides development of MMPs to reduce the threat to public health from mosquito-vectored pathogens. In general, the Service does not manage mosquitoes for mosquito-vectored animal disease. Mosquito management actions, such as managing non-native mosquitoes that threaten endangered species, would follow another plan, such as an exotic animal or invasive species management plan or an endangered species recovery plan that includes a National Environmental Policy Act analysis, and an Endangered Species Act consultation, if appropriate.

VI. Mosquito-Vectored Pathogen Surveillance and Mosquito Monitoring

∑ Describe the pathogen surveillance and mosquito monitoring activities used to direct mosquito management.

Refuge staff, public health authorities, and mosquito control organizations must rely on mosquito pathogen surveillance (referred to as "pathogen surveillance" throughout the remainder of the handbook) and mosquito monitoring to direct mosquito management activities in order to be most effective and minimize non-target impacts. In general, Refuge Managers may authorize, but do not implement, disease surveillance and mosquito monitoring. There must be mosquito monitoring or pathogen surveillance data to support treatment decisions. The refuge staff evaluates the mosquito monitoring data results against Action Thresholds to guide mosquito management decisions.

The Refuge Manager must:

- Identify the public health agency or mosquito control organization who will conduct pathogen surveillance and mosquito monitoring on or near the refuge and include the contact information and their roles in the MMP.

- Identify the on-refuge restrictions and stipulations in a Special Use Permit (SUP) for mosquito monitoring and pathogen surveillance activities (e.g., access, vehicle use, sensitive species and/or habitats, time of day) to protect sensitive resources while still allowing activities needed to make decisions.

- Document the communication and notification procedures between the public health agency (or their authorized representative) and the refuge.

- Review the monitoring and pathogen surveillance protocols (including objectives, methods, frequency, and locations) and include them in the MMP (and reference in the SUP); these protocols are more appropriate in the MMP than in the Inventory and Monitoring Plan for the refuge.

- Archive mosquito monitoring and pathogen surveillance protocols and data reports in PRIMR and ServCat, respectively.

Mosquito-vectored pathogen surveillance data will include vector abundance (larval and adult forms) and may document mosquito-based pathogen infection rates on- and off-refuge. Monitoring vector-mosquito abundance and pathogen-related data, such as dead bird surveillance and human disease cases, can serve as the basis for decision-making and the thresholds for pesticide treatment. Mosquito management is adaptive management, where mosquito activity is identified and quantified, perhaps treated, and re-checked periodically, often every 7 to 14 days, for activity status and, if necessary, treatment effectiveness.

Mosquito-borne Pathogen Surveillance

The purpose of mosquito-borne pathogen surveillance on or near the refuge is to provide the refuge staff information to make informed decisions regarding responses to mosquito activity. Public health authorities and mosquito control organizations conduct mosquito-borne pathogen identification and surveillance. Detecting the mosquito-borne pathogens includes testing adult mosquitoes for pathogens or testing reservoir hosts for pathogens or antibodies.

This is not a refuge function. Request copies of the surveillance protocols that the local public health authority and/or mosquito control organization use. Surveillance of mosquito-borne pathogens may:

- Confirm the mosquito species vectoring a pathogen.

- Identify locations where mosquitoes vectoring pathogens breed on-refuge.

- Confirm pathogen incidence/prevalence.

- Confirm the seasonality of pathogen prevalence (as appropriate).

- Identify and confirm locations where pathogens (human or wildlife) occur.

Mosquito Monitoring

Mosquito monitoring identifies the mosquito species present, relative abundance, and distribution. Mosquito monitoring is generally not a refuge function; public health or mosquito control organizations usually monitor for mosquitoes. Refuge staff should review the protocols used to determine that each step is appropriate on the refuge and that the data will be adequate to make decisions. Mosquito monitoring protocols should be standardized protocols that are included in the MMP, and referenced in the SUP. Repeated monitoring should reveal trends in mosquito production over time. Public health and mosquito control organizations use monitoring data that they collect with standardized methodologies to determine if, when, where, and how to treat; to assess effectiveness of treatment; and to map mosquito breeding and harboring areas to focus treatment strategies. Monitoring protocols are developed by the State or local public health authorities and mosquito control organizations.

Objectives for mosquito monitoring are to:

- Determine if areas on the refuge exceed established action thresholds as a basis to determine if treatment is warranted.

- Establish a baseline of mosquito species present and relative abundance.

- Identify mosquito source habitats and determine the relative contribution of refuge sources to the regional vector populations.

- Detect changes in relative abundance.

- Determine the seasonality for mosquito monitoring based on mosquito activity and lifestages.

The timing and frequency of monitoring is based on such factors as life histories of mosquito species present, tidal cycles (if applicable), water temperature, water levels in wetlands, timing, and volume of precipitation events, and available resources.

Following are examples of brief, summary descriptions of current mosquito monitoring protocols typically used by mosquito control organizations (consult local public health district or mosquito control organization websites for other standardized protocols):

1. Monitoring Larval Mosquitoes: The primary technique for larval population counts is the dip count (using a standard dip-cup on the end of a pole). Dips are taken in undisturbed pools identified as representative of the breeding areas. The trained field person avoids disturbing the water or casting a shadow over the water which will cause larvae to move/dive, thereby lowering counts. For large sites, dipping would likely be conducted at permanent, identified (or easily located) dip stations; although sampling location is often random. For small sites, dips may be taken at random locations throughout the site. Dips per site will be relative to the area needing sampling. Recommendations for treatment of an area may be determined with fewer dips if numbers of larvae and pupae per dip exceed action thresholds established in the refuge MMP (Walton, W. 2005).

Standards require field identification of larvae at least to the genus level. A trained observer can identify the following genera most of the time: *Aedes, Anopheles, Coquillettidia, Culex, Culiseta, Psorophora*, and *Uranetaenia*. If the common species in an area are known, a trained observer can often identify the larvae in the field; however, this is not always simple or reliable.

Identification keys for regions of North America are available for fourth instar larvae that have been collected and are examined under a microscope. Some mosquito control organizations raise numbers of larvae to adults in rearing chambers to confirm that the larvae found in the area (which could include a refuge) are the same species as the adults that are causing problems. There may be situations where treatment will depend on the mosquito species (as opposed to the genus) present. It is preferable that the public health or mosquito control organization staff trained in larval (4th instar) identification conduct this identification. Specimens can also be sent to local experts at State universities or extension offices to confirm identification and establish a reference collection.

2. Adult Mosquito Traps: A variety of adult mosquito traps are available for monitoring purposes: sticky surfaces; fans that draw mosquitoes into a trap; and some traps that use an attractant, such as CO2, that lures mosquitoes close enough to be drawn into a trap chamber. Traps are typically set out from sunset to sunrise to sample during periods when most species are actively dispersing and feeding. Counts of the species captured each trap night can indicate where adults are concentrating and how the adult populations are changing over time relative to control activities. Trap sites at the refuge boundary may identify that the species being produced on the refuge are dispersing to populated areas, although direction of flight can be difficult to discern. Mosquito control organizations sometimes use the number, frequency, and location of complaints from citizens regarding mosquitoes to help identify locations for mosquito monitoring, such as setting traps.

3. Landing Rate/Bite Counts: Although many historical datasets include landing rate counts, this is not a scientifically rigorous monitoring method and it is not recommended. For mosquito monitoring on national wildlife refuges, request that mosquito control organizations look for and implement other methods (see above). Landing rates, or bite counts, are equal to the number of mosquitoes landing on an observer in a pre-determined length of time, e.g., in 1 minute intervals. This method, when repeated at multiple locations, provides a rough, rapid assessment of the likelihood of being bitten in populated areas.

VII. Mosquito Management Options

∑ Describe the mosquito management options, including BMPs, habitat management, and products that may be used on the refuge.

Mosquito management options can include grounds-keeping activities and habitat manipulation to reduce breeding habitat, and, when necessary, may include the use of pesticides. When considering mosquito control measures, the Service authorizes those methods that present the lowest risk to our natural resources while still accomplishing the mosquito control goal. Always use BMPs preventively when implementing any treatment option, including pesticide treatments that may be considered. The table below provides BMPs to reduce mosquito breeding habitat in and around facilities.

Best Management Practices

Establish and implement a periodic review of facilities at risk for standing water:

- Minimize standing water to the maximum extent possible
- Remove/eliminate discarded tires, road ruts, open tanks, or similar debris/ containers
- Clear rain gutters to allow rainwater to flow freely
- Turn over containers that can hold water when stored outside
- Check for trapped water in tarps used to cover boats/equipment and arrange covers to drain water
- Pump out boat bilges
- Replace water in birdbaths and livestock troughs twice a week
- Fix outside water faucets that are dripping.
- Use screens on rain barrels and water cisterns

Habitat manipulations for mosquito management (such as draining or maintaining high water levels) that conflict with wildlife management objectives are prohibited except when it is necessary to temporarily suspend, allow, or initiate mosquito management activity in a refuge to protect the health and safety of the public or a fish or wildlife population, as provided in section 8 *Emergency Power* of the National Wildlife Refuge System Improvement Act of 1997.

Managing Habitats for Mosquito Source Reduction

Source reduction is a commonly used term in mosquito management. Whether a refuge has bogs, swamps, salt marsh, or freshwater marsh habitats (collectively referred to as wetlands), water circulation is a natural function that impedes production of mosquitoes. Since European settlement, wetlands have been altered or degraded by various practices such as grazing, farming, ditching, and construction of roads and bridges. Unaltered wetlands are rare, and source reduction techniques are not permitted in these unique wetlands. In some cases, restoration of degraded or previously altered habitat can be an effective and economically viable option to accomplish mosquito source reduction while also restoring natural hydrological function. In contrast, weirs, dams, or missing or undersized culverts inhibit natural water flow that may promote a low-flow environment for eggs to hatch and adults to emerge before being flushed out of the system. Mosquito population reduction may occur when a tidal marsh habitat is managed to drain effectively or high marsh ponds are created or restored to serve as reservoirs for fish that then control mosquito larvae. Native fish throughout the country continue to provide effective mosquito control in natural habitats. In coastal salt marshes, species such as *Fundulus heteroclitus*, and other cyprinid fish can exert control over mosquitoes in the egg, larval, and pupal stages (Rochlin et al. 2012).

Flowing water is a poor producer of mosquitoes because egg masses are destroyed and larvae and pupae drown. Restricting the flow of streams and rivers or channelizing these waterways may reduce riffles and rapids, which reduces flow so that mosquitoes can breed and reproduce effectively. Maintaining or restoring the meander and streambed topography will restore hydrology that naturally prevents streams and rivers from being sources of mosquitoes. This also diversifies the system, providing habitats conducive to mosquito predators both in and out of the water.

Aquatic habitats should be supported by natural hydrological processes, where possible. To do so may require researching historic flow conditions, consulting a hydrologist or restoration ecologist, and coordinating with landowners up- and downstream to re-establish natural flows and conditions. You may need to clear channels of accreted sediment, and remove or enlarge structures to increase water flow into and out of the system. This may require some adaptive management before the natural flows return, where channels scour properly, and water flows are regular and consistent through the system. Wetland enhancements may re-create channels to drain or flood a poorly circulating habitat. Engineering a tidal marsh restoration should ensure wetlands have adequate circulation to almost completely drain the marsh and allow flood-up at regular daily tide cycles. Similarly, stream restorations should be engineered to keep water moving.

Marsh alterations, whether for source reduction or marsh enhancement have not been without unintended consequences. Ditches used to drain mosquito breeding habitat on the East Coast also drained high marsh pools and salt pannes important for waterfowl and shorebirds (Cottam 1938). Projects designed to restore natural hydrology may also fail if, after restoration, they produce excessive mosquito populations adjacent to local communities where there previously was not a mosquito breeding issue. For this reason, we should continually make efforts to develop integrated, ecologically-sound approaches for marsh alteration that not only restores natural function, but also does not create mosquito breeding habitats.

The decision to consider a particular marsh for physical alterations should begin with local, site-specific data and documentation that describes the need for a management decision. If physical marsh management is appropriate, the Refuge Manager may invite a technical advisory committee (TAC) of Service staff and external scientists as well as local partners, such as mosquito control organizations, to help evaluate a suite of potential marsh alterations. The TAC recommendations may include type, extent, intensity of alterations, and physical and biological metrics for post-alteration monitoring. Use BMPs during restoration to avoid heavy equipment ruts, fill subsidence, or any other action that may result in unintended temporary pools of standing water.

Establishing and maintaining positive working relationships is important when working with mosquito control organizations, other State and Federal agencies, and private contractors. The refuge staff will work with them from the initial contact and planning phases through implementation, monitoring, and evaluation to adopt marsh management techniques that enhance fish and wildlife benefits for the public while limiting the creation of mosquito breeding habitats.

Mosquito Control

∑ Describe the mosquito control techniques and pesticides that may be used on the refuge. The information below may help you make better informed decisions.

Mosquito control can be accomplished with prevention techniques, habitat management practices, pesticides, and biological controls. Each Regional office's Integrated Pest Management (IPM) Coordinator reviews proposed uses of pesticides in coordination with the National IPM Coordinator. The public health authority or mosquito control organizations and the Refuge Manager must use data from various sources (e.g. scientific literature) to identify control products and ensure new products and technologies are reviewed as they become available. The MMP should include all potential products that may be used. In most instances, refuge staffs do not apply pesticides for the control of mosquitoes. If the Refuge Manager authorizes mosquito pesticide application through a SUP, the pesticide may be applied by the public health authority or a mosquito control organization. The Refuge Manager must understand the treatment options and consequent risks to non-target resources, and require the use of IPM principles to minimize pesticide use and impacts. Refuge staff may work with the Regional IPM Coordinator or Service environmental contaminants staff to make an appropriate choice of pesticide-based control products. Use local mosquito monitoring data provided by the public health authority or the mosquito control organization when considering the pesticide products. Pesticide active ingredients described below can be used to develop an MMP and to prepare for discussions with public health authorities or mosquito control organizations.

Mosquito Control Pesticides

Mosquito control pesticides can be categorized into three classes: larvicides, pupacides, and adulticides. There are relatively few products available within each of these classes, and all differ with regard to efficacy and effects on non-target organisms. Active ingredients in these pesticide products may include: chemicals, naturally occurring bacteria, analogs of insect molting hormones, and monomolecular oils as well as inert ingredients. The USEPA registration process for pesticide products considers primarily the toxicity and environmental persistence of the active ingredient. In many pesticide products, the active ingredient is combined with "inert" ingredients that alter the environmental behavior of the chemical. All inert ingredients in USEPA registered pesticide products are pre-approved before being used in a pesticide product formulation (USEPA 2015). These inert ingredients are added to increase activity or modify a physical property such as increase the bulk of the product, lengthen its persistence in the environment, or otherwise improve its ability to reach the target species. While these inert ingredients are not intended to have non-target toxicity, in some cases they do.

If mosquito control measures using pesticides are necessary, the Refuge Manager's next goal is to ensure that the public health authority or mosquito control organization selects products for on-refuge use that minimize natural resource non-target impacts. Products allowed for use on-refuge should correspond with the information known about:

- Mosquito species and targeted life stage
- The breeding habitat
- Density of larval populations
- Temperature
- Efficacy of the products
- Potential impacts to non-target resources
- Resistance management
- Costs

Following the long-standing IPM principles, the Service continually strives to minimize exposure of non-target refuge natural resources to pesticides. Therefore, in general mosquito adulticide products are not used on refuges. Larvicides are preferred over mosquito adulticides for several reasons:

- Use of mosquito larvicides prevents the appearance of the blood feeding adults
- Mosquito larvicides can provide up to a month of control, rather than the few hours or days provided by fogging with adulticides
- The commonly used mosquito larvicides are less toxic than the adulticides and are applied in such a way that there is much less human exposure
- Mosquito larvicides generally are applied to smaller areas than are adulticides

Larvicides. Larvicides are pesticides that affect the four instars of mosquitoes. The most common mosquito larvicides are derived from natural bacteria or act on insect-specific pathways not shared by other insect species. Spinosad, s-methoprene, and *Bacillus*-based *Bacillus thuringiensis israelensis (Bti)* or *Lysinibacillus sphaericus (Ls)*, the main active ingredients, have unique routes of exposure and modes of toxicological action against larval mosquitoes. The route of exposure and mode of action influence their non-target toxicity relative to each other and to other types of chemical insecticides. They can be applied through a variety of methods including hand application via backpack sprayers, low-pressure amphibious tracked vehicles, truck-mounted equipment, and aerial sprayers. Spinosad and s-methoprene work via contact rather than ingestion. *Bacillus*-based products have lower risk to non-target organisms in part because they must be ingested by the insect and are activated at a high pH that occurs almost solely in the gut of mosquitoes, midges, and black flies. As with all pesticide use in the Service, we review and approve or decline to approve the use of larvicides through the Pesticide Use Proposal System.

Preferred Active Ingredients

Bacillus thuringiensis israelensis (Bti) is a natural soil bacterium that acts as a larval mosquito stomach poison. *Bti* must be ingested by the larval form of the insect in order to be effective. *Bti* contains crystalline structures that have protein endotoxins that are activated in the alkaline conditions of an insect's gut. These toxins attach to specific receptor sites on the gut wall and, when activated, destroy the lining of the gut and eventually kill the insect. The toxicity of *Bti* to an insect is directly related to the specificity of the toxin and the receptor sites. Without the proper receptor sites, the *Bti* will pass through the insect's gut. *Bti* is most effective on first, second, third and early fourth instar larvae. The earlier instars feed at a faster rate (late fourth instar larvae feed very little) and require ingestion of fewer crystals to induce mortality. *Bti* has been shown to have toxic activity against mosquitoes, black flies, and certain species of midge; no direct effects of *Bti* toxicity have been found for aquatic invertebrates and this profile is preferred for use on a refuge. *Bti* has limited acute and no chronic toxicity to mammals, birds, fish, or vascular plants (USEPA 1998). *Bti*-based products with labels indicating efficacy for 1-2 weeks are preferred for use on refuges, however a number of product labels indicate efficacy for up to 40 days, and the activity of Briquet formulations can last for months.

Lysinibacillus sphaericus (Ls) is a registered larvicide, and few field studies have examined its non-target effects. Data available indicate a high degree of specificity of *Ls* for mosquitoes, with no demonstrated toxicity to midge larvae at mosquito control application rates (Mulla 1984; Ali 1986; Lacey 1990; and Rodcharoen 1991). Some *Ls* product labels indicate effects lasting for as long as four weeks.

Less Preferred Active Ingredients

Spinosad is derived from two fermentation products of a soil actinomycete bacteria (*Saccharopolyspora spinosa*), the spinosyns A and D. Spinosad is a contact neurotoxin that disrupts the nicotinic acetylcholine receptors in insects. This mode of action is similar to that of the neonicotinoid insecticides, and similar to the organophosphates which act on a different receptor in the same biochemical system. Due to the mode of action on a pathway that is conserved across taxa, spinosad acts on a broad array of insects. Products designed to increase the environmental persistence of spinosad have been found to enable target (mosquito) and non-target toxic effects that can persist for several weeks (Duchet et al. 2015; Lawler and Dritz 2013). Due to spinosad's mode of action that impacts a diversity of aquatic invertebrates and its persistence, this active ingredient is less preferred for use on-refuge than the *Bacillus*-based products.

S-methoprene is a synthetic mimic of the naturally produced insect juvenile hormone (JH); it is commonly referred to as an insect growth regulator. Mosquitoes produce JH in the larval stages, with the highest levels occurring in the early developmental stages. As an insect reaches the final stages of larval development, the JH level is low. This low level of JH triggers the development of adult characteristics. When S-methoprene is applied directly to larval mosquito breeding habitat, the mosquito larvae will continue to feed and may reach pupal stage, but the S-methoprene interferes with the maturation of the pupa and they will not emerge as adults. The mosquito third and fourth larval instars are the most susceptible stages of development when exposed to S-methoprene. Mammals, birds, fish, reptiles, and amphibians do not have this juvenile hormone nor do they share this biochemical pathway, which is what makes S-methoprene a relatively targeted insecticide. S-methoprene is essentially non-toxic to mammals, has some limited toxicity to birds, amphibians, fish, and certain non-target freshwater invertebrates, and some marine crustaceans, that share similar biochemical pathways to those on which S-methoprene acts in target organisms. Hormones act on biological systems at exceedingly low levels, thus, a very low concentration of S-methoprene is required in the environment to control target organisms. This fact, combined with its low toxicity to birds and mammals makes S-methoprene a useful mosquito larvicide alternative that can be used in an integrated approach. Products are available in several formulations: liquid, granular, pellet, and briquette. There are several extended-release formulations that remain effective for up to 150 days. Due to the fact that S-methoprene can act on invertebrates that share the juvenile hormone and biochemical mode of action as well as the active ingredients persistence, it is less preferred for use on refuges (Pinkney et al. 2000).

Not Recommended for Use on Refuges

Organophosphate mosquito larvicides (e.g., temephos) inhibit the enzyme acetylcholinesterase by binding it irreversibly and cause cumulative effects in animals repeatedly exposed to these chemicals. This biochemical pathway is essential to nerve function in insects, humans, and other animals, and the effects of exposure are cumulative, therefore, safer alternatives are preferred. The USEPA banned most residential uses of organophosphates in 2001, but they are still used in agriculture and for control of larval mosquitoes.

Surface Oils and Films. Surface oils and films are applied to aquatic mosquito breeding sites to kill mosquito larvae and pupae. The products create a barrier to the air-water interface and suffocate the insects, which generally require periodic contact with the water surface to obtain oxygen. Surface oils can prevent female mosquitoes from landing to lay eggs. Due to the broad-spectrum action of surface oils and films, they are not appropriate and are rarely authorized for use on refuges. The oils are mineral based and are effective for 3-5 days. Surface films are alcohol-based and produce a monomolecular film over the water surface. Both oils and the films are potentially lethal to any aquatic insect that lives on the water surface or requires periodic contact with the air-water interface to obtain oxygen. Surface oil is effective against all immature stages through suffocation; but studies have demonstrated negative effects on water surface-dwelling insects from applications of oils (Mulla and Darwazeh 1981; Lawler et al. 1998). Surface oils may also adversely affect wildlife, such as oiling the feathers of young waterfowl and other birds. This may be of particular concern at low temperatures when the oil and lack of feather function could affect thermoregulation (Lawler et al. 1998). If these are proposed for use on refuge by a public health representative or mosquito control organization and mosquito management has not been achieved through the use of larvicides, the refuge staff may work with a Service toxicologist to evaluate the risk to non-target resources and consider the use through the Pesticide Use Proposal System and NEPA analysis.

Mosquito Adulticides. Adulticides are broad-spectrum insecticides used to control adult mosquitoes in the short term. Most active ingredients in these pesticides pose significant ecological risk to non-target organisms and for this reason they are not appropriate and are rarely authorized for use on refuges. Adulticides may be used in a declared public health emergency, or in rare instances when prevention, BMPs, larvicides and pupacides have failed to provide the level of control necessary to protect public health. It is important to work with mosquito control organizations to provide input about sensitive refuge resources when these pesticides are proposed for use on or adjacent to the refuge.

State and local agencies commonly use the organophosphate insecticides malathion and naled and the synthetic pyrethroid insecticides prallethrin, etofenprox, pyrethrins, permethrin, resmethrin, and sumithrin for adult mosquito control. These insecticides are applied as aerial (helicopter or fixed-wing) sprays or truck-mounted ground-based fogs as ultra-low volume (ULV) sprays (very fine droplets). Only truck-mounted or backpack sprayers can be used to apply adulticides in tight or confined areas. Aerial drift is a part of application because these sprays are most effective on, and are intended to target, flying insects. For this reason, these pesticide applications often occur in the evening or early morning hours when the majority of mosquito species are active.

The two classes of adulticides (pyrethroids and organophosphates) work on the nervous system, but through different modes of action. The pyrethroids are sodium channel blockers and are less toxic than organophosphates to birds and mammals, however, pyrethroids are toxic to fish, bees, and other pollinators. Pyrethrins are naturally occurring compounds extracted from chrysanthemum plants (McLaughlin 1973, Klassen et al. 1996, Todd et al. 2003). Pyrethroids have similar molecular structure to pyrethrins, but are synthetically derived. Organophosphates act on the neurotransmitter, cholinesterase, which is shared widely across taxa including humans.

Pyrethoids/Pyrethrins. The most common pyrethroids are the synthetics: prallethrin, etofenprox permethrin, resmethrin, and sumithrin. The pyrethroids and pyrethrins are usually combined with the synergist compound, piperonyl butoxide, which interferes with an insect's detoxifying mechanisms (Tomlin 1994). Non-target toxicity may occur in either terrestrial or aquatic species as a result of deposition, runoff, inhalation, or ingestion. Pyrethroids, although less toxic to birds and mammals, are toxic to fish and aquatic invertebrates (Anderson 1989; Siegfried 1993; Tomlin 1994; Milam et al. 2000).

Pyrethroid-based products are sometimes used as barrier treatments in mosquito control. Bifenthrin is one active ingredient used in barrier treatments, but it is persistent, impacts a broad spectrum of insects, and generally is not appropriate for use on a refuge. Barrier treatment involves spraying pesticides at close range with a high velocity nozzle, discharging to the vegetation, essentially forming a barrier that is toxic to mosquitoes entering the treated area. However, not all mosquito species are impacted equally by the barrier treatments (Doyle et al. 2009; Hurst et al. 2012); exposure to rain and sunlight can affect bifenthrin barrier sprays (Allan et al. 2009), and it is highly toxic to bees. To minimize non-target effects to bees, barrier applications can be made late in the day, giving the active ingredient time to break down overnight (Qualls et al. 2010). If pyrethroid-based barrier treatments are proposed for use adjacent to refuge habitat, it will be important for the refuge staff to work with the mosquito control organization and share information about sensitive refuge natural resources to minimize and avoid adverse impacts.

Organophosphates. Organophosphates, such as malathion and naled, affect the nervous system by disrupting the enzyme that regulates the neurotransmitter, acetylcholine. Organophosphate insecticide toxicities vary, but some are very poisonous and impact non-target species; however, they are generally not persistent in the environment. Non-target species can have an indispensable ecological role in the environment and their disappearance or decline may negatively impact ecological processes and/or adversely affect food webs and other aspects of ecological community structure (Bretaud et al. 2000). Naled is a commonly used organophosphate for the control of adult mosquitoes, but it is rarely used on-refuge due to its known non-target impacts.

Mosquito Control Active Ingredients

The table below shows the active ingredients in mosquito control products and their appropriateness for use on refuges when mosquito control is warranted to protect human health.

Larvicides[1]	Larvicides/Pupacides[2]	Adulticides[3]
Lysinibacillus sphaericus	*S*-methoprene	Malathion
B. thuringiensis israelensis	Spinosads (spinosyn A and D)	Naled
Temephos	Oils	Prallethrin
	Films	Etofenprox
		Pyrethrins
		Permethrin
		Resmethrin
		Sumithrin

[1]Preferred active ingredients for use on NWRs, these target mosquito larvae.

[2]Less preferred active ingredients for use on NWRs because methoprene is an insect growth hormone (IGH) regulator. All insects have the IGH and potential adverse effects are also possible to threatened and endangered invertebrates, particularly crustaceans. Spinosads affect a broad spectrum of aquatic larval insects, and oils and films create a barrier to the air-water interface that can suffocate a diversity of insects requiring periodic contact with the water surface to obtain oxygen.

[3]Not recommended for use on NWRs. Temephos, malathion, and naled are organophosphates that impact a broad spectrum of insects over a relatively short period of time. Control is, therefore, short-lived. Prallethrin, etofenprox, pyrethrins, permethrin, resmethrin, and sumithrin are pyrethroids that are highly toxic to fish, aquatic invertebrates, and bees.

MODIFIED MOSQUITOES

Mosquitoes can be modified in several ways that can help reduce transmission of mosquito-borne diseases. Extensive testing and a rigorous regulatory process will occur before any modified mosquito use is authorized by Federal regulators. When registered for use in the United States, emerging technologies, such as modified mosquitoes, that accomplish the mosquito management objective at reduced risk to the environment may be considered by the Service. One method of modification, known as the sterile insect technique (SIT), relies on the production and release of sufficient numbers of sterile males of a target mosquito species into the natural population. Sterilization occurs by radiation, genetic manipulation, or other techniques. The female mosquito need only mate once in her life to trigger egg production sufficient to produce several batches of eggs. If a female mates with a sterile, or modified, male then it will not produce viable offspring. Ultimately, if sterile or modified males are released in sufficient numbers over time, it may result in the local elimination or suppression of the mosquito population and potentially reduce the spread of disease.

An alternative strategy focuses on reducing the ability of the mosquito to transmit disease. One technique to accomplish this involves the introduction of a gene (a transgene) from one species into a living organism causing the recipient organism to exhibit a new property and transmit that property to its offspring. Another technique involves infecting mosquitoes with a bacterium that impairs their ability to be infected with or transmit a virus or other pathogen. With these techniques, the goal is to develop mosquito strains that are unable to support development or transmission of pathogens that impact human health, and then introduce that trait into mosquito populations.

If a Refuge Manager is approached with a federally registered modified mosquito control option and is considering this for the purposes of wildlife conservation, the Refuge Manager should collaborate with the Service IPM Coordinator and review the proposed use through Appropriate Use, Compatibility, and Biological Diversity and Environmental Health policies, the Endangered Species Act, and NEPA.

Modified Mosquitoes for Avian Recovery in the Pacific Islands

Currently 28 species of endemic Hawaiian forest birds are listed as vulnerable, threatened, or endangered. The introduction of the mosquito *Culex quiquefasciatus* to the Hawaiian Islands, and then subsequently *Plasmodium relictum* (the parasite that causes avian malaria) and avian pox virus have heavily impacted the native bird populations in Hawaii. Increases in the prevalence of these mosquito-borne diseases, and concurrent decrease in forest bird densities, suggests that diseases are contributing to the population declines. Avian malaria is a serious threat to remaining Hawaiian forest birds. Mitigating effects of introduced avian disease is an action to recover Hawaii’s native avian species as stated in the Service’s Revised Recovery Plan for Hawaiian Forest Birds.

Some progress has been made in developing modified mosquitoes for disease control to protect human health and several techniques have achieved proof-of-principle in laboratory studies. While we anticipate continued advances in techniques to achieve long-term vector control, application of these technologies to the avian disease problem may also someday be feasible.

VIII. Thresholds for Action - Risk Management

∑ Develop and state the thresholds at which actions will be implemented.

Departmental and Service policies authorize Refuge Managers to allow native mosquitoes to exist unimpeded unless they interfere with site management goals or jeopardize human health and safety. Refuge Managers may work with others to minimize public health risks due to mosquitoes on refuges. Surveillance and monitoring data is a primary tool to inform managers so that they make the best decision about managing mosquitoes with public health agencies or mosquito control organizations. The public health authority or a mosquito control organization implements pesticide treatment control actions to minimize mosquito-borne pathogens after coordination and if authorized by the Refuge Manager.

The Service applies a science-based process using quantitative information to make decisions. Understanding stakeholder needs, including their perceptions of risk, is important and useful in effectively communicating the Service's mosquito management strategies. For helpful guidance on communicating about the MMP and strategy, see the section in this handbook on "Education and Outreach." The Service's

Table 1. Factors to Identify and Describe in Mosquito Management Plans

Factor	Factor Description	Importance in Management
Mosquito Species	Identify species; ability to vector pathogens; flight distances; feeding preference (e.g., birds, mammals, humans); seasonality of occurrence; breeding habitat; intrinsic population growth rate (univoltine [1 brood/season] vs. multivoltine.)	The species (and their characteristics) that occur on -refuge will direct mosquito monitoring and treatment /management options to consider. Species characteristics regarding pathogen vectoring are more important in determining treatment than the relative abundance.
Presence / Absence of Mosquito-Vectored Pathogen	Identify past monitoring data/results of wildlife, mosquito sources, horse, sentinel chicken (or other species), and human mosquito-borne diseases.	Absence or presence of pathogens and prevalence will influence the decision to allow or not allow mosquito management activities (e.g., monitoring/surveillance, treatment/management.)
Public Health Agency	Identify the nearest public health /vector control agency that covers the site.	Public health is responsible for declaring public health emergencies, threats, and advisories. They may also conduct pathogen or disease surveillance and/or mosquito monitoring.
Mosquito Control Organizations	Identify the nearest mosquito control organization that covers the site. Resources available for mosquito management vary among locales.	These agencies often have historic and or current disease surveillance and/or mosquito monitoring data for the surrounding community. Plan monitoring/surveillance and the treatment/management options that are permissible on a refuge, if necessary.
Mosquito Habitats	Identify and map the mosquito breeding habitat on-refuge, such as degraded marsh or wetland habitats. Breeding habitat is species-specific.	If the refuge has primary breeding sites for mosquitoes that may affect (vector pathogen) human health, treatment may be necessary. Treatment options may include pesticide application or habitat restoration. If refuge mosquito habitats are insignificant in the context of the landscape, no treatment may be necessary.
Proximity to Human Populations	The distance from identified mosquito habitat on-refuge to human population centers (numbers and density).	In some instances, the potential to produce large numbers of mosquitoes in close proximity to human population centers may result in mosquito control on refuge lands and waters to minimize disease risk due to mosquito pathogens.
Water and Vegetation Management	Identify mosquito habitats, if they exist at the site, as well as where management of water level and/or vegetation can be accomplished in an effort to reduce mosquito productivity.	There may be instances where we can control mosquitoes on a refuge through habitat management; this may pose the least risk to refuge natural resources.
Weather Patterns	Historic and current: prevailing wind directions, precipitation, and temperatures. (Note: with climate change, new trends in weather patterns in the area may be emerging).	Prevailing wind patterns that carry mosquitoes from refuge habitats to population centers may drive mosquito management actions. Inclement weather conditions may prevent mosquitoes from moving off-refuge, resulting in no treatment.
Refuge Access	Identify points of access for monitoring and/or implementing mosquito management actions to avoid impacts to sensitive areas.	For refuges with limited access, such as designated wilderness areas or critical habitat, monitoring and/or treatment access may not be allowed or may be prescribed.
Water Quality and Quantity	Characterize water quantity (flow) and quality (e.g., dissolved oxygen, pH, salinity, and organic content) at the refuge mosquito breeding habitats.	Flow or lack thereof, dissolved oxygen levels, and organic content in water may increase or decrease mosquito productivity (abundance); salinity affects the types of mosquitos that are likely to be present.

Integrated Pest Management policy is to manage pests by combining physical, biological, cultural, and chemical tools in a way that minimizes environmental, health, and economic risks. The process described in this handbook is intended to minimize risk to natural resources if and when the Refuge Manager authorizes others to manage mosquitoes on refuge to protect public health as guided by public health authorities or other designated representatives.

Many factors influence decisions related to mosquito management on a refuge. Table 1 outlines factors to identify and describe in an MMP. This table should be populated with refuge-specific information when preparing an MMP. Once complete, refuge staff may review these Table 1 factors in combination with mosquito monitoring and pathogen surveillance information when deciding the appropriate mosquito management actions, including potentially allowing the application of pesticide.

Pesticide Treatment Decisions Based on Absence/Presence of Mosquito-Borne Pathogens and Minimizing Health-Related Risks Due to Mosquitoes

Decisions about pesticide treatment on refuges are based on the absence/presence of mosquito-borne pathogens and minimizing risk from mosquitoes that vector pathogens that may cause disease in humans. Work closely with the local public health agency or mosquito control organization to develop a reasonable approach to determine responsible and protective on-refuge control measures. Pathogen surveillance and mosquito monitoring data from the surrounding area and on the refuge help us to make the best decisions about the response. These data are collected by public health authorities or a mosquito control organization. Mosquito vectored pathogens may be isolated to certain areas although mosquitoes are present throughout much of the United States. In the absence of current pathogen surveillance data, public health authorities or mosquito control organizations may use historical information about mosquito-vectored pathogens cycling in an area to determine whether there might be a current health risk. If a Refuge Manager is approached about allowing larvicide treatment of mosquitoes on a refuge, he/she must request the data from on-refuge and near-refuge surveillance and monitoring. With a proposal for use of pesticide treatments other than larvicides, the Refuge Manager must request a determination or confirmation that there is a risk to public health from mosquitoes on the refuge. While studies have indicated that the incidence of disease and immune-compromised conditions could be linked to mosquito numbers, that relationship has yet to be identified. Several studies have shown, however, that an increase in mosquito activity may translate to a commensurate increase in disease risk and other immune response reactions (Liu et al. 2009; Ruiz et al. 2004; Whelan et al. 2003). While not precise and not a preferred method, mosquito numbers can be used to determine how to carry out pesticide treatments to minimize risk of disease, if the assumption that increased numbers of mosquitoes pose a commensurate increase in disease risk is accepted. This approach provides the opportunity to work with public health agencies or mosquito control organizations toward a quantifiable method for decision making. A Refuge Manager must consider the moderating factors in Table 1 when a treatment threshold is based on mosquito species and life-stage numbers. Table 2 presents proposed actions to minimize risk from mosquitoes.

A public health agency or a mosquito control organization should propose an on-refuge action threshold they developed using supporting documentation, such as the monitoring and surveillance data. Although there is more than one approach to deriving action threshold values, the values should be based on historical and current data collected with scientifically sound protocols. The goal is an action threshold for treatment that will reduce potential disease risk, while using mosquito control treatments that pose the lowest risk to on-refuge non-target resources. Threshold values generated through this approach should be adjusted whenever more scientifically rigorous monitoring or surveillance data becomes available to ensure adequate risk reduction. Pesticide treatment on-refuge should not occur without an action threshold agreed upon by the refuge staff and the public health agency or their designated representative or the mosquito control organization, if need be.

Below are two possible options to derive action threshold values (see Appendix C for an example). The goal is threshold values that balance response to public health concerns and protection of on-refuge natural resources by using the lowest risk treatments and minimizing treatment frequencies.

Option 1 –
Mosquito Counts, deviation from the mean
Using historical or current mosquito monitoring data (e.g., species and dip counts, trap counts), a threshold value could be set at a level that deviates

from the mean (e.g., one or two standard deviations above the mean), assuming adequate sample size. For assistance in determining adequate sample size, consult a Service environmental contaminants biologist or ecotoxicologist, an Inventory and Monitoring Coordinator, or the Regional IPM Coordinator.

Option 2 –
Mosquito Counts, mass emergence avoidance

Another option is to evaluate mosquito species and life-stage data and counts in terms of mosquito larvae numbers that would trigger a mosquito fly-off (i.e., large dense mosquito emergence). Changes in water levels may trigger activation of dormant eggs, which will then result in an increased larval count. Monitoring would be conducted and treatment and control actions implemented to ensure large mosquito emergence events do not occur. The assumption is that by reducing mosquito larvae numbers to the point of avoiding or reducing the likelihood of a mass mosquito emergence/fly-off event, the likelihood of disease associated with such an event (mass emergence) is reduced. Once action threshold values are derived, use a matrix such as Table 2 to guide mosquito management actions.

Table 2. Treatment Decisions Based on Mosquito-Borne Pathogen Risk Minimization
Consider the moderating factors in Table 1 to evaluate refuge response when presented with mosquito-vectored pathogen surveillance and monitoring data. Note: numeric action thresholds may be different for historic pathogens/disease only and pathogen/disease documented in the current year.

Current Conditions		Action Level	Refuge Response
Documented Mosquito-Borne Pathogens or Vectoring Mosquitoes	**Refuge Mosquito Populations[2]**		
No documented current or historical pathogens.	An action threshold is not applicable.	**1**	Remove/manage artificial mosquito breeding sites such as gutters, tires, tanks, or similar debris/containers. Implement BMPs. Allow mosquito monitoring and pathogen surveillance on-refuge, as appropriate. Generally, no pesticide treatment is appropriate.
Documented mosquito species known to vector pathogens occur in the area (there may also be supplementary evidence of pathogens in sentinel organisms or humans.)	Below action threshold	**2**	Respond as in Action Level 1, plus: consider allowing appropriate and compatible monitoring and disease surveillance. Consider appropriate and compatible non-pesticide management options to reduce mosquito production (see BMPs and habitat management actions). Allow mosquito monitoring and pathogen surveillance on-refuge, as appropriate. Generally, no pesticide treatment (such as applying larvicide) is appropriate, because numbers are below the action threshold.
	Above action threshold	**3**	Respond as in Action Level 2. Allow mosquito monitoring and pathogen surveillance on-refuge, as appropriate. The refuge may allow application of larvicide. If pupacides, surface films or oils, or adulticides are being proposed for use on refuge: • Request public health documentation of need for treatment • Use the Table 1 Factors to determine whether or not to authorize treatment. • Select the least toxic chemical that achieves the goal. • Prepare and implement a refuge Non-Target Resources Monitoring Plan (see paragraph below for information on Non-Target Resources Monitoring Plan).

Mosquito adulticide use on refuge lands or waters is not consistent with Service policy (e.g., IPM (569 FW 1), Compatibility (603 FW 2), Biological Integrity, Diversity, and Environmental Health (601 FW 3)), should be extremely rare, and only be used if larvicides/pupacides:

(1) Did not provide effective treatment to control mosquitoes, and

(2) A public health agency or an authorized representative determines and states in writing there is risk to public health from mosquitoes on-refuge.

Refuge Managers and public health agencies or mosquito control organizations must carefully evaluate the use of mosquito adulticides adjacent to refuge lands and waters as drift may impact refuge resources. Refuge Managers can preemptively develop a Pesticide Drift Monitoring Plan for impacts to sensitive species when a mosquito adulticide is authorized on-refuge for public health protection. Drift monitoring is a task that the mosquito control organization completes. Service toxicologists and Environmental Contaminants specialists in Ecological Services field offices have expertise to help prepare a plan. Alternatively, Refuge Mangers may work with mosquito control organizations to develop a plan. Such practices as implementing no-spray zones or spray drift buffers can provide avoidance and minimization of impacts to refuge lands or waters and other sensitive resources.

Human Health Emergencies

When there is a declared emergency that requires a response action that may have a significant environmental impact, emergency NEPA regulations must still be followed (see 40 CFR 1506.11 Emergencies). Generally, agencies limit actions to those necessary to control the immediate impacts of the emergency. The Service's Compatibility policy (603 FW 2) describes, in part, the emergency authorization provided in the Administration Act as follows: "Authority to make decisions under this emergency power is delegated to the Refuge Manager. Temporary actions should not exceed 30 days and will usually be of shorter duration. The Refuge Manager will create a written record (memorandum to the file) of the decision, the reasons supporting it, and why it was necessary to protect the health and safety of the public or any fish or wildlife population."

IX. Natural Resource and Compliance Monitoring and Reporting

∑ Describe the natural resource and compliance monitoring that will be used and reporting requirements.

Natural Resource Monitoring

The Refuge Manager must ensure that the effects of mosquito management actions on the refuge's natural resources are monitored. This monitoring provides information to help make future decisions and to take immediate steps to minimize adverse effects on non-target resources. Baseline monitoring establishes resource conditions prior to implementation of mosquito control activities, such as physical habitat alterations or persistent pesticides. Refuge staff may work with Inventory and Monitoring and Environmental Contaminants biologists to determine appropriate baseline monitoring metrics for the refuge species, habitat, and resources. The Refuge Manager should inform the mosquito control organization that issuance of an SUP for control activities may require that they conduct natural resource monitoring to ensure mosquito management activities are not impacting resources on the refuge. If refuge natural resources are not monitored by experts within Service programs, refuge staff should work collaboratively with the mosquito control organization to ensure there is information on impacts of mosquito control activities to biological resources. The refuge may choose to implement or oversee studies on biological impacts to sensitive resources (perhaps federally listed insects).

Mosquito Management Implementation Compliance Monitoring

Mosquito management compliance monitoring is necessary to assess the efficacy of treatment and compliance with stipulations. When permitting mosquito control activities on the refuge include requirements within the MMP and SUP to assess the efficacy of methods and compliance with the plan. For example, if the MMP and SUP dictate wind speed restrictions on aerial applications of pesticides to avoid drift on refuge lands and waters, require the mosquito control organization to conduct compliance monitoring on the refuge for the presence and concentration of the pesticide. Monitoring to detect pesticide drift, to confirm pesticide product application rate and concentration efficacy, and to detect impacts to resources may be required under the conditions of the SUP. Monitoring will provide data to evaluate compliance with wind speed and direction restrictions and help determine if the parameters adequately protect refuge resources. Monitoring other types of control activities may also be required to help refuge staff and mosquito control organizations ensure effectiveness of treatments and provide information to minimize pesticide use. This data helps refuge staff make informed decisions on mosquito management while reducing non-target natural resource and environmental risk due to intrusive methods and application of pesticides. In addition, Terms and Conditions resulting from ESA consultations for mosquito control activities may also require monitoring to ensure that actions taken are in compliance.

Reporting

The Refuge Manager should require mosquito control organizations to prepare an annual summary report of refuge mosquito monitoring and surveillance results and any control activities that were authorized on the refuge (e.g., pesticide product(s) applied, amount of pesticides applied, locations of application, method of application). Reporting requirements should be listed in the SUP.

The annual summary report may include maps showing geo-referenced locations where management activities occurred; pesticide usage; efficacy; and comparisons of mosquito control activities within and among years to show trends that may indicate success of habitat management efforts or suggest the need for a new management approach. Some of this information is required as part of the Pesticide Use Proposal and Usage Report (see 569 FW 1). Enter reports into ServCat as a resource for the refuge staff and others in the Service.

Mosquito management activities on refuges require an ongoing commitment to assess, monitor, and revise methods and approaches to ensure that refuges' resources are protected over time. Thorough reporting is an important part of the process.

X. Adaptive Management

> ∑ Describe the adaptive management approach that will be practiced in mosquito management on the refuge.

Adaptive management is a systematic approach for improving resource management by learning from management outcomes (Sexton et al.1999). Mosquito management falls within the range of disciplines and partnership responsibilities that would benefit from an adaptive management approach. Refuge Managers should use the adaptive management approach to refine on-refuge mosquito management and control actions within and among seasons and to address complex natural resource issues that may be impacted by mosquito management activities. This will be done in cooperation with the mosquito control organization.

Refuge staff should identify the alternatives to meet the refuge's mosquito management objectives, predict the outcomes of alternatives based on the current state of knowledge, implement one or more of the alternatives, monitor to document and evaluate impacts of the mosquito management actions, and then use the results to adjust future mosquito management actions (Murray and Marmorek 2004). This is important because pesticide formulations, toxicity data and information on natural resource sensitivities are constantly being updated. Adaptive management focuses on learning and adapting, through partnerships of managers, scientists, and other stakeholders who together create and maintain sustainable resource systems (Bormann et al. 2006).

XI. Education and Outreach

> ∑ Describe the education and outreach information that will be available to communicate about mosquito management on the refuge.

The Service should provide education and outreach materials that communicate the Service's mosquito management actions to staff, volunteers, visitors, and the public. Refuge staff should be prepared to speak directly with visitors and have printed information available on personal safety and mosquitoes on the refuge.

Local Mosquito Situation and Communication

The public may express concern when mosquito control programs take place on or near a refuge that has sensitive, threatened, and endangered species. There may be concern regarding application of pesticides on natural areas or the use of modified mosquitoes. Some sectors of the community may advocate for mosquito control, while other sectors of the population may advocate for a Refuge Manager to do nothing about mosquitoes. For these reasons, the Refuge Manager must prepare clear and simple education and outreach materials to address the diverse perspectives encountered and to ensure that refuge staff and volunteers understand his/her decisions.

Refuge staff and volunteers should develop a basic understanding about the mosquito species on the refuge, including life history and the species ability to vector disease. This information is on the Centers for Disease Control and Prevention website and describes how mosquito-borne diseases are transmitted and includes personal protection recommendations.

General visitor education and outreach information can consist of fact sheets and kiosk postings informing visitors to use protective garments and to consider bug repellents so they will enjoy visiting the refuge. Consider providing information on the mosquito species present on the refuge and information on any diseases those mosquitoes vector. The following information could be provided at a Visitor Services kiosk and some may also be used as talking points:

- Tips on mosquito control at home such as emptying buckets, cleaning bird baths and gutters, draining water that collects on equipment covers, and securing door and window screens
- Personal precautions to prevent against mosquito bites: wearing long sleeves, pants, socks, and sometimes applying repellents
- Describe actions to reduce mosquito production on the refuge
- Explain the role of mosquitoes in the ecosystem, such as their role as food for other wildlife, including both aquatic and terrestrial species
- Highlight that mosquitoes are nectar feeders, they visit plants in bloom and, thus, are pollinators
- Not all mosquito species are vectors of disease. Know the facts about mosquito species in the area and whether or not they vector pathogens that cause disease
- Some mosquito control methods may harm other wildlife, especially other insects, and habitats. Know the facts on non-target effects of control on the refuge

Mosquito control organizations may also have public affairs specialists on staff. Advice from such specialists can help the Refuge Manager articulate to the public the reasons for conducting or not conducting mosquito control actions. Communicating risk management to the public is important. Understanding stakeholder needs, including their perception of risk of disease, is useful in effectively communicating the Service's mosquito management decisions. Refuge Managers may work with Service External Affairs staff to develop talking points prior to implementing management actions to respond to questions from the media and the public about decisions to control or not control mosquitoes on the refuge.

PREVENTION

Personal Protective Measures

- *Make sure window and door screens are "bug tight." Repair or replace, if needed.*
- *Stay indoors at dawn and dusk when mosquitoes are the most active.*
- *Wear a long sleeve shirt, long pants, socks, and a hat when going into mosquito-infested areas such as wetlands or woods.*
- *Use mosquito repellant, when necessary, and carefully follow directions on the label.*
- *For insect repellent information, refer to the Centers for Disease Control and Prevention, https://wwwnc.cdc.gov/travel/yellowbook (accessed 6/28/18)*

Protect Animals of Concern

- *To protect horses and domesticated animals, talk to your veterinarian about vaccines, repellants, and other measures. Thoroughly clean livestock watering troughs weekly.*

For more information: https://www.cdc.gov/onehealth/basics/zoonotic-diseases.html (accessed 12/02/2016).

Natural Mosquito Predators

Although natural predators may help with mosquito control, they cannot completely solve the problem. Dragonflies, aquatic bugs, aquatic beetles, crustaceans, amphibians, fish, bats, and birds all feed on a variety of prey, including mosquito adults and larvae. In some instances, natural predators are efficient at controlling mosquito populations, such as in artificial ponds or containers. For example, crustaceous copepods are tiny, voracious predators of mosquito larvae and have been used successfully in the targeted control of container-breeding mosquitoes (Soumare and Cilek 2011). Habitat that supports native predators can serve as a visible and complementary mosquito control mechanism. The Biological Integrity, Diversity, and Environmental Health policy (601 FW 3) prohibits the introduction of species on refuges outside their historic range, and this includes consideration of non-native mosquito predators. The public may express interest in the following natural predators of mosquitoes; and refuge staff can share the following information with the public, as regionally appropriate.

Purple Martins and Other Birds

A literature review on the role of purple martins in mosquito control (Kale 1968) concluded that (1) mosquitoes appear to be a negligible item in the diet of the purple martins; (2) behavior patterns of mosquitoes and martins are such that most mosquitoes are not flying in purple martin feeding areas when martins are active; and (3) no evidence exists that any avian species can effectively control a species of insect pest upon which it feeds when that pest is at or near peak abundance. However, bird boxes on refuges near visitor centers can spark conversations about the value of these species in our ecosystems.

Bats

Bats are opportunistic feeders. Bats in the wild consume mostly larger prey such as beetles, wasps, and moths, where mosquitoes represent less than 1 percent of their total diet (Easterla and Whitaker 1972; Vestjens and Hall 1977; Sparks and Valdez 2003; Whitaker and Frank 2012). Nevertheless, refuge staff can use bat houses as an outreach education tool given the ecosystem benefits that bats offer, and the fact that many bat species are declining over much of their ranges.

Dragonflies and Damselflies

The aquatic stage of these species is most effective as a mosquito predator; adults of most of these species are not active during the hours that mosquitoes are flying (Pritchard 1964, Walton 2003). These species require a habitat similar to mosquitoes; the standing water needed to support them also support mosquitoes. These species work best under specific conditions such as in small artificial ponds or other containers of water where there are few other insects to eat besides mosquito larvae, no vegetation for the mosquitoes to hide in, and no competing fish or other wildlife. Purchased dragonflies and damselflies may not be local species; introducing them into the local ecosystem is not in compliance with the Service's biological integrity policy (601 FW 3).

Fish

Gambusia (mosquitofish) are native to the Atlantic and Gulf slope drainages and the Mississippi River basin. Gambusia have been stocked (often for mosquito control) in 38 states. Outside of their native range, Gambusia are considered invasive. They can flourish in many habitats and are known to be opportunistic and voracious predators, also eating the eggs, larvae, and young of native fish and amphibians. Combined with their high fecundity rate, Gambusia can out-compete native fish species, affect local amphibian populations, and overwhelm other local native mosquito predators, including dragonflies and native minnows. The Service biological integrity policy (601 FW 3) does not support introduction of non-native species for mosquito control on a refuge, however, see 601 FW 3.14 F for exceptions. Minnows, killifish, mummichogs, other small fish species that inhabit marshes eat mosquito larvae and pupae.

Glossary

Action Thresholds. Levels that trigger actions to manage mosquitoes.

Adaptive Management. Adaptive management is a systematic approach for improving resource management by learning from management outcomes.

Adulticide. A pesticide that kills adult mosquitoes.

Appropriate Use. A proposed or existing use on a refuge that meets at least one of the four conditions identified in the Appropriate Refuge Uses policy (603 FW 1).

Biological Diversity. The variety of life and its processes, including the variety of living organisms, the genetic differences among them, and communities and ecosystems in which they occur (see 601 FW 3 for more information on biological diversity).

Biological Integrity. Biotic composition, structure, and functioning at genetic, organism, and community levels comparable with historic conditions, including the natural biological processes that shape genomes, organisms, and communities (see 601 FW 3 for more information on biological integrity).

Compatibility Determination. A written determination signed and dated by the Refuge Manager and Regional Refuge Chief signifying that a proposed or existing use of a national wildlife refuge is a compatible use or is not a compatible use (see 603 FW 2 for more information on compatible uses).

Environmental Health. Composition, structure, and functioning of soil, water, air, and other abiotic features comparable with historic conditions, including the natural abiotic processes that shape the environment (see 601 FW 3 for more information on environmental health).

Enzootic. A relatively consistent prevalence of disease in animals. The term is comparable to endemic, but refers to animals.

Health Threat. An indication of an impending adverse impact to public health from mosquito-borne disease, as identified and documented by Federal or State public health authorities, and/or a designated representative. Health threats are based on the presence of endemic or enzootic mosquito-borne pathogens that cause disease, including the historical incidence of disease, and the presence and abundance of vector mosquitoes as documented by current monitoring and surveillance of mosquito vectors and mosquito-borne pathogens.

Integrated Pest Management (IPM). A sustainable approach and principles to manage pests with biological, cultural, physical, and chemical tools, used alone or in combination in a way that minimizes risk to health, the environment, and the economy (see 569 FW 1 for more information).

Larvicide. A pesticide that kills mosquito larvae.

Mosquito-Borne Disease. An illness produced by a pathogen that mosquitoes transmit to humans and other vertebrates.

Mosquito-Borne Pathogen Surveillance. Activities that a public health agency, or other authorized organization, conducts to detect pathogens causing mosquito-borne diseases. These activities include sample collection, testing adult mosquitoes for pathogens, or testing reservoir hosts for pathogens or antibodies.

Mosquito Control. Any activity designed to inhibit or reduce populations of mosquitoes. Activities include physical, biological, cultural, and chemical means of control directed against any life stage of mosquitoes.

Mosquito Monitoring. Activities that a public health agency, or other authorized organization, conducts associated with collecting quantitative data to determine mosquito species composition, mosquito population changes over time, locations of breeding and harboring habitats, and efficacy of control efforts (including resistance). It may include monitoring non-target natural resources for impacts.

Non-Target Resources. Species or habitats other than those targeted for treatment or control.

Pesticide Use Proposal (PUP). A PUP is the Service documentation we use to review and approve or disapprove the use of registered pesticides. The PUP includes a review of goals, objectives, IPM techniques, best management practices, treatment action thresholds, pesticide, pesticide application rates, equipment used, methods, application location, non-target species and natural resources in the action area, and a screening risk assessment.

Public Health Authority. A Federal, State, or local agency, or a designated authorized representative, that has staff with training and expertise in mosquitoes and mosquito-borne diseases and has the official responsibility to identify public health threats and determine when there is a risk for human health from mosquito-borne disease.

Pupacide. A pesticide that interferes with mosquito pupae development and survival.

Refuge-Based Mosquitoes. Mosquitoes produced (or occurring) on a refuge.

Reservoir Host. A species in which a pathogen is maintained over time. Reservoir hosts are fed upon by a vector which can then transfer the pathogen to another species.

Surveillance: Monitoring on a periodic schedule to observe and record certain actions or attributes.

Vector. An organism, such as a mosquito, that is capable of acquiring and transmitting a disease-causing agent, or pathogen, from one host to another.

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Appendix A

Authorities and Policies Relevant to Mosquito Management on NWRs

This section lists the laws, regulations, and policies relevant to mosquito management planning.

National Wildlife Refuge System Administration Act of 1966, as amended by the National Wildlife Refuge System Improvement Act of 1997 (Act) (16 U.S.C. 668dd-668ee) articulates management priorities for units of the Refuge System and governs refuge uses. Specifically, the Act prohibits uses that are not compatible with the purpose(s) of an individual refuge, maintenance of biological integrity, and the following mission of the Refuge System. *"The mission of the System is to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans."* The Refuge System is managed for wildlife conservation and also requires that six wildlife-dependent public uses be given priority consideration in refuge planning and management.

The Service uses regulations and policies to plan and guide mosquito management actions on refuges. Title 50 Code of Federal Regulations (CFR) Subchapter C, Part 25, Administrative Provisions, is where you find the enabling regulations of the Refuge System. Guiding policies are:

- Comprehensive Conservation Planning Process (602 FW 3)
- Step-Down Management Planning Policy (602 FW 4)
- Biological Integrity, Diversity, and Environmental Health (601 FW3)
- Integrated Pest Management (569 FW 1)
- Appropriate Refuge Uses (603 FW 1)
- Compatibility (603 FW 2)

National Wildlife Refuge System Regulations
Title 50 Code of Federal Regulations (CFR) Subchapter C, 25-38, Administrative Provisions, are Refuge System regulations as authorized by the Administration Act.

50 CFR 25.21 (a), (b), and (c) allow a Refuge Manager to take actions to protect public health, such as opening or closing a refuge, or temporarily allowing a particular use, such as mosquito management.

50 CFR 25.31 establishes requirements for notifying the public about changes to refuge uses.

50 CFR 25.41-43 establish responsibility and requirements for issuing or revoking refuge permits; they also describe the appeals procedure.

50 CFR 26.41 tells us how to determine whether a refuge use is a compatible use, meaning it will not materially interfere with or detract from the fulfillment of the mission of the Refuge System or the purposes of the refuge.

50 CFR 27.51 prohibits, except by special permit, disturbing, injuring, spearing, poisoning, destroying, collecting or attempting to disturb, injure, spear, poison (such as through the intended use of pesticides), destroy or collect any plant or animal on a refuge.

Comprehensive Conservation Planning policy (602 FW 3)
The Service's Comprehensive Conservation Planning (CCP) policy describes the process we use to establish long-range management direction to achieve refuge-specific purposes and fulfill the mission. CCPs may incorporate, but are not limited to, refuge-specific Integrated Pest Management (IPM) Plans, Invasive Species Management Plans, or Mosquito Management Plans. The Step-Down Management Planning policy (602 FW 4) allows for Step-Down Management Plans such as Integrated Pest Management Plans and MMPs that may be prepared to meet mosquito management goals and objectives identified in a CCP. Step-down plans must comply with NEPA.

Biological Integrity, Diversity, and Environmental Health policy (BIDEH, 601 FW 3)
The BIDEH policy provides for maintenance and restoration of healthy, functioning biological communities composed of native species and habitats. BIDEH favors refuge management which restores or mimics natural ecosystem processes or functions. The BIDEH policy generally discourages

controlling native species or using pesticides, yet acknowledges these actions may at times be necessary. Refuge Managers must assess any proposed mosquito management actions to ensure they meet the BIDEH requirements.

Integrated Pest Management (IPM) policy (569 FW 1)
The IPM policy allows the Service to manage pests. It defines pests as any living organism that may interfere with site-specific purposes, operations, or management objectives or that jeopardizes human health and safety. Under 569 FW 1.3 and 1.6, pests are managed when they interfere with site management goals and objectives, jeopardize human health or safety, or threaten wildlife health. Pests are also managed when their populations exceed action thresholds. An action threshold is the level of damage or number of pests at which a management action is implemented to control the pest population. The use of pesticides are authorized only after the Service evaluates a range of alternatives, including physical and cultural methods, biological controls, or taking no action at all. In doing so, human safety, environmental integrity, effectiveness of the action, and cost are considered. The IPM policy requires a Pesticide Use Proposal (PUP) be approved before a pesticide can be applied on a refuge. Depending on the specific pesticide proposed for use and the application method(s), approval of a PUP may reside with the Refuge Manager, Regional IPM Coordinator, or National IPM Coordinator.

Appropriate Refuge Uses policy (603 FW 1)
The Appropriate Refuge Use policy provides evaluation procedures (603 FW 1.11 A (3)) for Refuge Managers to ensure that new or existing management actions or methods are appropriate refuge uses. There are five types of refuge uses, and mosquito management to protect public health is covered under 603 FW 1.10D, Specialized Uses. A Refuge Manager must conduct an appropriate use evaluation and a proposed use must meet at least one of the following conditions to be determined appropriate:

- A wildlife dependent recreational use as identified in the Improvement Act
- A use that contributes to fulfilling refuge purpose(s)
- A use that involves the take of fish and wildlife under State regulations
- A use that has been evaluated and found to be appropriate

The Refuge Manager will address the condition criteria and analysis by completing FWS Form 3-2319 for each proposed use under review (see section 1.11 of 603 FW 1). The Refuge Manager retains the authority to reject or modify a use in accordance with this policy. An appropriate use evaluation is conducted prior to consideration compatibility.

Generally, mosquito management planning and actions are implemented on a refuge when necessary to protect public health.

Compatibility policy (603 FW 2)
The Compatibility policy and associated regulations (50 CFR 26.41) provide guidelines and direct Refuge Managers to ensure that a new or existing activity will not interfere with or detract from the fulfillment of refuge purpose(s) and the mission of the Refuge System. It also requires that the Service periodically review any use considered compatible to ensure that it complies with all applicable laws, policies, and regulations. If an action is found first to be appropriate and then compatible, the Refuge Manager may issue a Special Use Permit (SUP).

Mosquito inventory, monitoring, and control activities proposed may qualify as a "refuge use" in accordance with 603 FW 2. Compatibility Determinations (CD) must allow opportunity for public comment and be finalized in writing. Example CDs for mosquito management on refuges are available in the Refuge System Compatibility Determination database at https://systems.fws.gov/cdrmis/.

The Compatibility policy also states that a Refuge Manager must determine a use is not compatible if there is insufficient information to determine compatibility. Specifically, if there are insufficient management resources (e.g., funds, staff, facilities, and equipment) to ensure that a use would occur in a compatible manner, or if a use conflicts with the maintenance of refuge biological integrity, diversity, and environmental health, then the use is not compatible.

If a refuge Comprehensive Conservation Plan (CCP) included a CD on mosquito management activities, Refuge Managers should include that documentation in their MMPs. In this situation, there is no need to re-create this documentation unless circumstances have changed significantly.

When a public health agency or mosquito control organization proposes to conduct mosquito management activities on a refuge in support of the refuge purpose(s) and in the role of a Service-authorized agent, then that use qualifies as a “refuge management activity” and the Compatibility policy requirements do not apply. This may be applicable when mosquito inventory or monitoring is being conducted at the request of the Service.

Special Use Permits
The Refuge Manager issues Special Use Permits (SUPs) to authorize special uses on a refuge (see https://www.fws.gov/refuges/visitors/permits.html. Special Use Permits are issued for three categories of uses:

- Commercial Activities
- Research and Monitoring
- Other General Activity

A Refuge Manager may issue an SUP to allow appropriate and compatible inventory, surveillance and monitoring of larval, pupal, and adult mosquitoes and, if necessary, mosquito control activities. To avoid harm to wildlife or habitats, access to traps and sampling stations must meet the compatibility requirements found in 603 FW 2 and the activities are subject to refuge-specific restrictions, which should be clearly stated in the SUP.

The instrument used to document approval of the activity depends on why the activity is taking place. If only inventory, monitoring and surveillance are conducted, and no treatment actions will be implemented, these activities may be permitted under a Research and Monitoring SUP (FWS Form 3-1383-R, https://www.fws.gov/forms/3-1383-R.pdf, Memorandum of Understanding or other agreement). If a public health agency or mosquito control organization is conducting mosquito management activities on a refuge in support of the refuge purpose(s) and in the role of a Service authorized agent, then an agreement or contract is an appropriate instrument to guide their activities. Otherwise, conducting mosquito management on a refuge requires an Other General Activity SUP (FWS Form 3-1383-G, https://www.fws.gov/forms/3-1383-G.pdf.)

National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321-4347)
NEPA requires Federal agencies to consider the environmental effects of a proposed action in conjunction with an environmental review addressing among other things, impacts on social, cultural, economic, and natural resources. Agencies must consider a range of reasonable alternatives and the effects of their implementation.

A primary source of information for NEPA is found at https://ceq.doe.gov/ and in the Service’s *NEPA for National Wildlife Refuges, A Handbook* (https://www.fws.gov/policy/NEPARefugesHandbook.pdf). You may also contact a regional or the national Service NEPA Coordinator.

The Comprehensive Conservation Plan (CCP) that is prepared for every refuge is prepared as a NEPA document: an Environmental Assessment (EA), or sometimes as an Environmental Impact Statement (EIS). If mosquito management has been addressed in the CCP, including a discussion of environmental effects and alternatives, then the MMP can be prepared as a step-down plan of the CCP or of the Integrated Pest Management policy. If it was not addressed in the CCP, or only addressed superficially, then the MMP should be prepared as an EA.

Categorical exclusions (CatEx) are categories of Federal actions that do not have a significant effect on the quality of the human environment (individually or cumulatively). As such, these actions do not require preparation of an EA or an EIS. Use of a CatEx can be documented in an Environmental Action Statement or a memorandum to the file. A CatEx is an environmental review that does not require the extent of analysis that occurs in an EA or an EIS. The Service's CatEx list is in the Departmental Manual at 516 DM 8. Appendix 2 provides a list of Extraordinary Circumstances wherein the categorical exclusions would not apply. Section 2.4 on the extraordinary circumstances list states "Have highly uncertain and potentially significant environmental effects or involve unique or unknown environmental risks." Therefore, mosquito surveillance or monitoring activities may qualify for consideration as a CatEx; the application of pesticides would have measurable environmental impacts, and therefore, they may be precluded from CatEx consideration.

If the refuge has completed an MMP that reflects current activities and is NEPA-compliant, then it may be necessary to periodically review the MMP to ensure that it continues to comply with NEPA.

Endangered Species Act (ESA) of 1973, as amended (16 U.S.C.1531-1544)
The ESA provides for the identification, protection, and recovery of species approaching extinction. Protection of federally listed, proposed and candidate species and designated critical habitat can be achieved, in part, through section 7 of the ESA, which requires Federal agencies to consult with the Service or the National Marine Fisheries Service to ensure that any action an agency authorizes, funds, or carries out is not likely to jeopardize the continued existence of any federally listed species, or result in the destruction or adverse modification of designated critical habitat. Agencies consult with the National Marine Fisheries Service for listed species that inhabit marine environments during part or all of their life cycle (e.g., anadromous fish, marine mammals, and sea turtles when not nesting); otherwise, they consult with the Fish and Wildlife Service. The ESA Consultation Handbook can be accessed at https://www.fws.gov/endangered/esa-library/pdf/esa_section7_handbook.pdf

The actions proposed in an MMP, including but not limited to surveillance, monitoring, and control activities, are subject to a section 7 consultation whenever an activity may affect even a single individual of a listed, proposed, or candidate species, or an essential feature of its critical habitat. This consultation helps the Service to adequately evaluate risk, assess the effects of the physical activities, and evaluate ecotoxicological effects of pesticide products to these species and their critical habitats. This level of analysis is necessary for fauna and flora, as effects can be unusual and unexpected.

When contemplating actions associated with mosquito management, it is important that refuge staff contact their Regional IPM Coordinator and a Service contaminant specialist or ecotoxicologist early in the planning process to request necessary support. Consider starting with an informal consultation and engage Service environmental contaminants and section 7 experts as you prepare an effects analysis to evaluate potential ESA concerns. Identify ways in which to avoid or minimize adverse effects. Once avoidance and minimization measures are planned, it may be appropriate to consider compensatory mitigation measures for actions which cannot be avoided or minimized.

When a public health authority declares a public health emergency, the response is still subject to emergency consultation with the appropriate Service for endangered species issues. The ESA Handbook guides the emergency consultation process. Emergency consultations, by regulation, may occur shortly after response. Completing section 7 compliance documentation in conjunction with an MMP may allow the Refuge Manager to avoid emergency consultation if and when there is an unforeseen public health emergency.

Wilderness Act of 1964 (16 U.S.C.1132)
This Act allows Congress to designate wilderness areas that Federal agencies must manage to preserve their wilderness character and for

the use and enjoyment of the American people. As of 2016, there are 75 designated wilderness areas totaling 20.7 million acres within 63 refuges in 26 States. Proposed and designated wilderness areas are protected and managed to preserve natural conditions. Section 4(c) of the Wilderness Act generally prohibits temporary roads, motor vehicles, motorized equipment, motorboats, mechanical transport, landing of aircraft, structures, and installations. These general prohibitions may impact decisions related to mosquito management planning and proposed actions on or near designated wilderness. Proposed mosquito management treatments would be reviewed using the wilderness Minimum Requirements Analysis. Consult the multi-agency, Service-authorized website for information on the necessary Minimum Requirements Analysis at www.wilderness.net/MRA.

If there is proposed or designated wilderness on the refuge boundary, there may be special considerations for proposed mosquito management actions in wilderness. Consult the Service's policy website for the most up-to-date version of the Wilderness Stewardship policy (610 FW 1-5).

National Historic Preservation Act (NHPA) of 1966, as amended (16 U.S.C. 470)
Section 106 of NHPA requires Federal agencies to consider how their actions could affect historic properties. The legislation provides for preservation of historic and archaeological sites in the United States. NHPA created the National Register of Historic Places, the list of National Historic Landmarks, and the State Historic Preservation offices.

Archeological Resources Protection Act of 1979
The Archeological Resources Protection Act requires that archeological resources be identified and that proper permits be obtained prior to excavating any resources. Consider the requirements of NHPA and the ARPA if there is any mosquito management activity that might impact historic or archeologic resources. Ground disturbing activities, such as those associated with marsh habitat and hydrology restoration, and chemical treatments that might have reactions with sensitive structure materials should be evaluated. The Refuge Manager may need to coordinate with the appropriate State or tribal Historic Preservation office to ensure compliance with these Acts.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended. (7 U.S.C. 6) requires the U.S. Environmental Protection Agency to regulate activities related to pesticides. Regulated activities include: development, registration and classification, production, storage and transport, and application of pesticides to protect human health and the environment from unreasonable adverse effects.

Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands)
Executive Orders 11988 and 11990 direct Federal agencies to enhance floodplain and wetlands value, to avoid development in floodplains and wetlands whenever possible, and to minimize adverse impacts to them if development cannot be avoided. These may be applicable when considering open marsh water management and other restoration activities as part of an integrated MMP. The Refuge Manager may need to develop a Statement of Finding to address the requirements of these Executive Orders.

Clean Water Act (CWA), as amended. (33 U.S.C. 1251 et seq.)
The CWA establishes regulations for discharges of pollutants to waters of the United States. There may be permitting requirements regarding potential discharges of mosquito pesticides to waters and refuge staff should determine what, if any, requirements need to be addressed within the state and local jurisdiction.

Appendix B

Summaries of Common Mosquito-Borne Diseases and Related Health Considerations

Following are summaries of common mosquito-borne diseases and associated pathogens that occur or have occurred historically in the United States. Information is subject to change, so be sure to look for any updates when developing MMPs.

West Nile Virus (WNV) WNV is an arthropod-borne virus (arbovirus) in the family *Flaviviridae,* genus *Flavivirus* which is most commonly transmitted to humans by the bite of infected mosquitoes. WNV has been detected in a wide diversity of *Aedes, Anopheles, Culex, Culiseta*, and *Psorophora* species in the United States, as well as other less commonly encountered species. Mosquitoes become infected when they feed on infected birds. There are no medications to treat or vaccines to prevent WNV infection in humans. WNV can cause febrile illness, encephalitis (inflammation of the brain) or meningitis (inflammation of the lining of the brain and spinal cord). The incubation period is usually 2 to 14 days. Although most people infected with WNV will have no symptoms, about 1 in 5 infected people may develop a fever with other symptoms, and less than 1% of infected people develop a serious illness. WNV has been detected in all lower 48 States (not in Hawaii or Alaska) (Source: https://www.cdc.gov/westnile/faq/genQuestions.html (accessed 6/28/2018).

Dengue Dengue is a disease caused by any one of four closely related dengue viruses (DENV 1, DENV 2, DENV 3, or DENV 4). The viruses are transmitted to humans by the bite of an infected mosquito. The mosquito becomes infected with dengue virus after biting a person who has dengue virus in his or her blood. In the Western Hemisphere, the *Aedes aegypti* mosquito is the most important transmitter of dengue viruses, with *Ae. albopictus* also capable of transmitting the virus as well. Each year there are more than 400 million cases of dengue identified across the tropical urban areas of the world. The principal symptoms of dengue are high fever, severe headache, severe pain behind the eyes, joint pain, muscle and bone pain, rash, and mild bleeding (e.g., nose or gums bleed, easy bruising). Dengue Hemorrhagic Fever (DHF) is a severe form of infection; it can be fatal if unrecognized and not properly treated in a timely manner. Some people infected with the virus have no symptoms. Dengue is not spread directly from person to person. Dengue viruses may be introduced into new areas by travelers who become infected while visiting other regions where dengue commonly exists. (Source: https://www.cdc.gov/dengue/fAQFacts/index.html (accessed 6/28/2018).

Chikungunya The chikungunya virus is transmitted to people by *Ae. aegypti* and *Ae. albopictus* mosquitoes, the same mosquitoes that transmit dengue virus. They bite mostly during the daytime.The most common symptoms of chikungunya virus infection are fever and joint pain. Other symptoms may include headache, muscle pain, joint swelling, or rash. Symptoms usually begin 3 to 7 days after being bitten by an infected mosquito. Outbreaks have occurred in countries in Africa, Asia, Europe, and the Indian and Pacific Oceans. Chikungunya cases have been found in the Americas and on islands in the Caribbean and in Florida. Travel-associated cases have been documented in 43 states including Hawaii. There is no vaccine to prevent or medicine to treat chikungunya virus infection. (Source: https://www.cdc.gov/chikungunya/fact/index.html (accessed 6/28/2018).

La Crosse Encephalitis Virus (LACV) LACV is transmitted to humans by the bite of an infected mosquito. LACV is a California serogroup virus, in the genus *Bunyavirus*, family *Bunyaviridae*. Cases of LACV disease occur in the upper midwestern and mid-Atlantic and southeastern States. Many people infected with LACV have no apparent symptoms. Among people who become ill, initial symptoms include fever, headache, nausea, vomiting, and tiredness. Some of those who become ill develop more severe disease that affects the nervous system. There is no specific treatment or vaccine. Most people become infected from the "treehole mosquito" *(Ae. triseriatus)* which is an aggressive mosquito that bites during daytime. (Source: https://www.cdc.gov/lac/gen/qa.html (accessed 6/28/2018).

Eastern Equine Encephalitis Virus (EEEV) EEEV is transmitted to humans by the bite of an infected mosquito. EEEV is maintained in a cycle between *Culiseta melanura* mosquitoes and avian hosts in freshwater hardwood swamps. *Cs. melanura* is not considered to be an important vector of EEEV to humans because it feeds almost exclusively on birds. Transmission to humans requires mosquito species, such as some *Aedes, Coquillettidia*, and *Cule*x, that are capable of creating a "bridge" between infected birds and uninfected mammals. EEEV is a member of the genus *Alphavirus*, family *Togaviridae* and is a rare illness in humans; on average 6 cases are reported in the United States each year, mostly in the Atlantic and Gulf Coast states. Most people infected with EEEV have no apparent illness, but severe cases may affect the nervous system. There is no specific treatment or vaccine for EEE. (Source: https://www.cdc.gov/EasternEquineEncephalitis/ (accessed 6/28/2018).

Western Equine Encephalitis Virus The WEE was first isolated in California in 1930 and remains an important cause of encephalitis in horses and humans in North America, mainly in the western United States and Canada. In the western States, the enzootic cycle of WEE involves passerine birds, in which the infection is not apparent, and culicine mosquitoes, principally *Cx. tarsalis*, a species that is associated with irrigated agriculture and stream drainages. Other mosquito vector species include *Aedes melanimon* in California, *Ae. dorsalis* in Utah and New Mexico, and *Ae. campestris* in New Mexico (USGS 2013).

Human WEE cases are usually first seen in June or July. Most WEE infections are asymptomatic or present as mild, nonspecific illness. Patients with clinically apparent illness may have symptoms of fever, headache, nausea, vomiting, anorexia, and malaise, followed by altered mental status, weakness and signs of meningeal irritation. Children, especially those younger than one year old, may be affected more severely and 5-30% may be left with permanent after effects. The overall mortality rate is about 3%.

Expansion of irrigated agriculture in the North Platte River Valley during the past several decades has created habitats and conditions favorable to the increase in populations of granivorous birds such as the house sparrow and mosquitoes such as *Cx. tarsalis, Ae. Dorsalis,* and *Ae. melanimon*. These species may play a role in WEE virus transmission in irrigated areas.

No human vaccines are commercially available for this disease. Prevention includes: 1) personal protective measures such as reducing time outdoors, particularly in early evening hours, wearing long pants and long sleeved shirts, and applying mosquito repellent to exposed skin areas and 2) public health measures that may include use of insecticides to reduce disease-vectoring mosquito numbers. See https://www.health.state.mn.us/divs/idepc/diseases/weencephalitis/wee.html (accessed 12/2/2016), for more information.

Saint Louis Encephalitis Virus SLEV is transmitted to humans by the bite of an infected mosquito specifically *Culex sp.* mosquitoes *(Cx. Pipiens* and *Cx . quinquefasciatus* in the East, *Cx. Nigripalpus* in Florida, and *Cx. Tarsalis* and members of the *Cx. pipiens* complex in western States). Most cases of SLEV disease have occurred in eastern and central States. Although most people infected with SLEV have no apparent illness, symptoms may include fever, headache, nausea, vomiting, and fatigue. Symptoms of SLEV take 5 to 15 days to develop after the mosquito bite. Severe symptoms may sometimes occur. There is no specific treatment or vaccine. (Source: https://www.cdc.gov/sle/ (accessed 6/28/2018).

Zika Virus The primary mosquito species that transmit Zika virus are *Ae. aegypti* and possibly *Ae.. albopictus*, the same species that spread dengue and chikungunya viruses. These are aggressive daytime biters but they may also bite at night. Mosquitoes become infected when they feed on a person already infected with the virus. The adults feed almost exclusively on humans. Larvae can occur in man-made water holding containers that are often found near buildings. Both species are non-native to the Western Hemisphere and are dependent upon humans to maintain significant populations. A search of areas for water-holding containers (tires, cans, vases, etc.) and the removal of standing water should reduce risk associated with these artificial breeding environments. Symptoms of Zika virus range from no symptoms to fever, rash, joint or muscle pain, headache, or conjunctivitis (red eyes). A pregnant woman can pass Zika virus to her fetus during pregnancy. Zika is a cause of microcephaly and other severe fetal brain defects. Consult the Centers for Disease Control and Prevention website for more information. There is no vaccine to prevent or medicine to treat Zika virus. Personal protection from biting mosquitoes is the most effective form of prevention. (Source: https://www.cdc.gov/zika/ (accessed 6/28/2018).

Other Mosquito-Related Human Health Considerations

Most of the human population at any given time will have some reactivity to mosquito bites. Immediate reactions occur in 70% to 90% and delayed reactions in 55% to 65% of people bitten by mosquitoes (Peng et al. 1996; Oka and Ohtaki 1989). The incidence of self-reported large local reactions in one study was 2.5% (Arias-Cruz et al. 2006). Individuals at greatest risk are those with greatest potential exposure such as outdoor workers and those lacking acquired immunity (Crisp and Johnson 2013). Research indicates most people who experience immediate and delayed local reactions to mosquito bites that are immunologically mediated will see a decrease in reaction severity over time (Crisp and Johnson 2013; Peng and Simons 2007). An immune reaction is largely in response to proteins that exist within the mosquito saliva. Some 30 different proteins are present in the saliva and they include antiplatelet, anticoagulant, and vasodilator to facilitate feeding and sugar digestive and bacteriolytic enzymes (Crisp and Johnson 2013). Naturally acquired desensitization to mosquito saliva may occur during childhood or due to repeated exposure to mosquitoes (Peng and Simons 2007b). Desensitization through repeated exposure may take 2 to 20 years because people often attempt to limit their exposure due to the unwanted effects of the bites (Kulthanan et al. 2010). While mosquito allergies can be small to large and localized, others can be systemic. There is no specific threshold for number of bites that cause this effect, it is related to the specific health of the individual. A systemic reaction may be severe, and localized and occur in otherwise healthy individuals within hours of a mosquito bite, and last for 3 – 10 days. People at increased risk for severe reactions include those with high exposure (outdoor workers), those lacking acquired immunity (Peng and Simons 2007a; Simons and Peng 1999, McCormack et al. 1995) and those with primary or acquired immune-deficiencies, such as human immunodeficiency virus, and Epstein - Barr virus (EBV)-associated diseases (Asada 2007, Asada et al. 2003; Smith et al. 1993; Diven et al. 1988). With any break in the skin, there is the potential for secondary (indirect) bacterial infection resulting from mosquito bites. These issues may be minor and short-term and resolve without medical intervention.

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Simons, F.E.R. and Z. Peng. 1999. Skeeter syndrome. Journal of Allergy and Clinical Immunology 104:705-707.

Smith, K.J., H.G. Skelton, and P. Vogel. 1993. Exaggerated insect bite reactions in patients positive for HIV. Journal of the American Academy of Dermatology 29:269-272.

Appendix C
Action Thresholds

Example: No Name Key Florida Light trap counts dataset

SYSTAT Rectangular file C:\Users\lhribar\Documents\mydoc\Everything from old machine\nn12.syz, Created data file Thu May 16 13:33:51 2013 containing variables

In the example data here: From light trap counts, the Mean is 61 mosquitoes, the Standard Error around that Mean is 20. The Mosquito Control Authority might select "80" (60 + 20) as the Action Threshold; OR, more conservative, the Standard Deviation is 150, the Action Threshold could be set at 150. There are some outliers in the dataset, such as Day 128 with more than 900 mosquitoes, that tends to make the Standard Deviation quite large.

Descriptive Statistics	TOTAL
N of Cases	51
Minimum	0.000
Maximum	946.000
Range	946.000
Sum	3,124.000
Interquartile Range	44.250
Median	9.000
Arithmetic Mean	61.255
Standard Error of Arithmetic Mean	20.877
Mode	0.000
95.0% LCL of Arithmetic Mean	19.323
95.0% UCL of Arithmetic Mean	103.187
Geometric Mean	.
Harmonic Mean	.
Standard Deviation	149.088
Variance	22,227.314
Coefficient of Variation	2.434
Skewness (G1)	4.630
Standard Error of Skewness	0.333
Kurtosis (G2)	25.459

Standard Error of Kurtosis	0.656
Day of Year	Total Mosquitoes
3	0
9	1
17	0
25	0
30	0
38	0
44	5
52	138
58	25
65	1
72	1
79	2
86	1
93	0
100	3
108	26
115	5
122	162
128	946
135	145
142	87

150	140
156	393
163	12
170	9
177	6
184	210
191	78
198	10
208	124
212	51
219	3
233	7
241	1
248	138
254	262
261	0
268	16
275	13
283	5
289	28
296	1
304	9
310	21
318	2

324	0
331	12
338	0
345	0
352	9
362	16

Appendix D

Animal Health Considerations

West Nile Virus (WNV) continues to cause illness and death in wild birds since its introduction to North America in 1999. The initial wave of the virus swept from east to west across the country, causing mortality events in corvid species (e.g., crows, jays). Now, WNV is endemic in the United States and has caused occasional focal outbreaks in white pelicans, eared grebes, and bald eagles. Eastern and Western Equine Encephalitis Viruses (EEEV and WEEV), St. Louis Encephalitis (SLEV), and La Crosse Encephalitis (LaCEV) Viruses also cause low levels of illness and death in wild birds (Ladeau et al. 2007).

Efforts to control mosquito-borne diseases usually target areas with high human population densities. Many control methods are not particularly effective over large natural areas, and are not appropriate as a tool for preventing mosquito-borne diseases in domestic animals or wildlife. Mosquito-associated wildlife diseases are considered to be a natural part of the ecosystem.

Avian malaria is transmitted by mosquitoes to endemic bird species in Hawaii and the Pacific Islands and has contributed to their extinction. No mosquito species are native to the Hawaiian Islands. Mosquito management actions specifically for the benefit of the native birds may be appropriate when following an exotic animal plan that includes a NEPA analysis.

There are several mosquito-borne diseases that impact domestic and other animals. For dogs and cats, heartworm (*Dirofilaria immitis*) can be a life-threatening disease. The disease is caused by a roundworm. Dogs, cats, foxes, and raccoons can be infected with the worm through the bite of a mosquito carrying the larvae. Cases of heartworm have been reported in all 50 States and in several provinces of Canada. Sixteen species of mosquitoes in the genera *Aedes*, *Ochlerotatus*, *Anopheles*, *Culex*, and *Psorophora* are vectors for heartworm. (Source: http://www.mosquito.org/mosquito-borne-diseases, American Mosquito Control Association,

Three of the mosquito-borne diseases listed in the human health section above (WNV, WEE, EEEV) also pose health risks for horses. These viruses are associated with fever, lack of appetite, and lethargy, progressing to various degrees of excitability, followed by drowsiness. They ultimately end in paresis, seizures, and coma in fatal cases. Vaccines are available for these diseases. Some domesticated birds (e.g., emus, Peking ducks) are severely affected by EEEV.

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